HAND BOOK of the FARM SERIES

EDITED BY J. CHALMERS MORTON.

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THE CHEMISTRY OF THE FARM

BY

R. WARINGTON, F.C.S.

BRADBURY AGNEW & Co 9. BOUVERIE ST.

LONDON

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EDITED BY J. CHALMERS MORTON,

EDITOR OF THE "AGRICULTURAL CYCLOPÆDIA;" THE "AGRICULTURAL GAZETTE;"
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LONDON:
BRADBURY, AGNEW, & CO., 9, BOUVERIE STREET.
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THE present Volume is the first of a *series of five*—the others discussing the Live Stock and the Crops of the Farm, the Soil and its Tillage, and the Equipment of the Farm and the Estate. Each book will be complete in itself, and the whole will form a *Handbook of the Farm* adapted to the wants of the teacher and the student of agriculture. The remaining volumes of the series will appear as they are ready. Among the names of the writers engaged on them are W. T. CARRINGTON, G. MURRAY, T. BOWICK, G. GILBERT, S. SPENCER, W. BURNESS, J. C. MORTON, and others.

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PREFACE.

THERE is perhaps scarcely any need for an apology in bringing out a new work on a branch of science which develops at such a rapid rate as Agricultural Chemistry. In the case of such a science the lapse of a few years must find any text-book, however good, more or less deficient in important particulars. We might, however, urge a special reason on the present occasion, namely, the scarcity of books on farm chemistry in the English language. Our countrymen have indeed conducted many notable investigations on the chemistry of the soil, plant, and animal, and the papers containing their results rank among the classics of our scientific literature; but of text-books for students, discussing agricultural chemistry as a whole, we have scarcely any, and none

perhaps in which the present aspects of the science are at all adequately represented.

The present little book is primarily intended to supply a demand, which we believe is gradually arising, for the teaching of agricultural science in our schools; it is intended as a small text-book for the use of teachers, expressing briefly, and we hope clearly, the principal facts which form the basis of agricultural chemistry. Though intended thus in a special manner for teachers, we hope it may prove useful to all who may wish to become students of the subject. When used by a teacher the matter should be taken a little at a time, and enlarged upon in the course of the lesson. Particular opportunity for enlargement is furnished by the tables contained in the book; the facts they represent, being self-evident on a consideration of the figures, are often very slightly alluded to in the text, but are left to the observation and study of the reader.

It is assumed that those who use this book will have a general acquaintance with the facts of elementary chemistry; a knowledge of these must

precede any study of the particular chemistry of plants or animals. It is also very desirable that something should be known of the structure, and processes of life in plants and animals; such knowledge is quite essential for clear ideas on agricultural science. The teacher or student thus furnished will be the one best able to make use of the special information which it is the object of the following pages to convey.

It may perhaps be of service to mention a few books which will be found useful by the student. Among works on plant physiology we may name the Text-Books of Botany by Thomé, and by Prantl (Vine's translation), and the still more elementary work by McNab. "How Crops Grow" is an excellent work, but is, we fear, out of print.

In animal physiology Huxley's Elementary Lessons may be particularly recommended.

"How Crops Feed" is an excellent work, chiefly devoted to the chemistry of soil; it is now somewhat old.

There are also two capital little German works by E. Wolff, embracing the whole subject of

agricultural chemistry; these are, "Praktische Düngerlehre," and "Landwirthschaftliche Fütterungslehre."

The best English work on agricultural chemistry exists as yet only in detached papers. The numerous reports containing the Rothamsted investigations on the chemistry of crops and animals will be found chiefly in the Journal of the Royal Agricultural Society.

R. W.

May, 1881.

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THE

CHEMISTRY OF THE FARM.

CHAPTER I.

PLANT GROWTH.

The Constituents of Plants.—Water—The combustible elements of vegetable matter—The proportion of ash constituents in various parts of plants—The essential and non-essential elements of the ash—Composition of a crop of grass. *Function of the Leaves.*—Assimilation of carbon from the air—Formation of vegetable substance—Plant respiration—The transpiration of water. *Function of the Roots.*—Absorption of ash constituents and nitrogenous matter from the soil—The excretion of useless matter by the plant—The part played by ash constituents. *Germination.*—General character of seeds—The conditions and processes of their germination. *Plant Development.*—Annual plants—the order in which plant constituents are assimilated—Biennial and perennial plants—the storing up of food for a second season—spring sap rich in sugar.

THE first step towards a knowledge of plant chemistry must be an acquaintance with the materials of which plants are built up.

The Constituents of Plants.—The most abundant ingredient of a living plant is water. Many succulent vegetables, as turnips and lettuce, contain more than 90 per cent. of water. Timber felled in the driest time seldom contains less than 40 per cent. of water.

If a branch of a tree is burnt, the greater part is consumed and passes away in the form of gas, but there is left behind a small quantity of white ash. The same happens if any other part of a plant is burnt. The constituents which form the dry matter of plants may be thus conveniently divided into two classes—the combustible and the incombustible.

The combustible part of plants is made up of five chemical elements—carbon, oxygen, hydrogen, nitrogen, and sulphur; without these no plant is ever produced. Carbon generally forms about one-half of the dry combustible matter of plants. Nitrogen seldom exceeds 4 per cent. of the dry matter, and is generally present in much smaller amount. Sulphur is still smaller in quantity. The remainder is oxygen and hydrogen.

The carbon, hydrogen, and oxygen form the cellulose, lignose, pectin, starch, sugar, fat, and vegetable acids which plants contain. The same elements united with nitrogen form the amides and alkaloids; and further united with sulphur the still more important albuminoids, which are essential constituents of all plants.

The incombustible or ash constituents form generally but a small part of the plant. The timber of freely-growing trees contains but 0.2—0.4 of ash constituents in 100 of dry matter. In seeds free from husk the ash is generally 2—5 per cent. In the straw of cereals 4—7 per cent. In farm roots 4½—8 per cent. In hay 5—9 per cent. It is in leaves, and especially old leaves, that the greatest proportion of ash is found; in the leaves of root crops the ash will amount to 10—25 per cent. of the dry matter.

The incombustible ash always contains five chemical

elements—potassium, magnesium, calcium, iron, and phosphorus, besides sulphur already mentioned. Iron is present in only very small quantity. These five elements, though forming a very small portion of the plant, are indispensable to its life. Besides the elements just named, an ash will generally contain sodium, silicon, and chlorine, with frequently manganese, and perhaps minute quantities of other elements. The supplementary elements just named are not apparently essential to plant life, though some of them discharge useful functions in the plant.

The metals above-named occur in the plant as salts, being combined with phosphoric, nitric, sulphuric, and various vegetable acids, of which oxalic, malic, tartaric and citric acid are the most common. The metals are also sometimes present as chlorides. Phosphorus occurs in the form of phosphates; silicon is present as silica. Sulphur occurs partly as sulphates, and partly as a constituent of albuminoids. In the ash of plants the nitrates, and the salts of the vegetable acids are found in the form of carbonates.

It is common to speak of the combustible ingredients of a plant as "organic," and the incombustible ingredients as "inorganic." This distinction is scarcely accurate, as those ash constituents which are indispensable parts of plants have, during the plant's life, as much right to be called "organic" as albumin or cellulose.

In the following table will be found the average composition of a crop of meadow grass weighing 5 tons when cut, and producing $1\frac{1}{2}$ ton of hay; this will illustrate what has just been said as to the constituents of plants. Further information as to the composition of crops will be found on page 38.

COMPOSITION OF A CROP OF MEADOW GRASS.

Water			8,378 lb.
Carbon	.1315	Combustible matter	2,613 lb.
Hydrogen	144		
Nitrogen	49		
Oxygen and Sulphur	.1105		
Potash	56.3	Ash	209 lb.
Soda	11.9		
Lime	28.1		
Magnesia	10.1		
Oxide of iron	.9		
Phosphoric acid	12.7		
Sulphuric acid	10.8		
Chlorine	16.2		
Silica	57.5		
Sand, &c.	4 5		
Total crop			11,200 lb.

Plants obtain the elements of which they are built up partly from the soil, and partly from the atmosphere. From the soil they obtain, by means of their roots, all their ash constituents, all their sulphur, and nearly the whole of their nitrogen and water. From the atmosphere they obtain, through the instrumentality of their leaves, the whole, or nearly the whole, of their carbon, with probably small quantities of nitrogen and water.

Function of the Leaves.—The source of vegetable carbon is the carbonic acid gas present in the atmosphere. Carbonic acid gas passes more readily through the cuticle of a plant than do the nitrogen and oxygen which make up the bulk of the atmosphere. The carbonic acid thus absorbed is decomposed within the chlorophyll cells of the plant under the influence of light, oxygen being evolved, and the carbon retained by the plant. All green parts of a plant probably share in this action, but it is pre-eminently

the function of the leaves. The decomposition of carbonic acid does not proceed in darkness, or at a very low temperature. The rays of light most active in effecting the decomposition are the yellow and orange rays; the blue, violet, and dark red rays of the spectrum have scarcely any influence.

The oxygen gas given off by a green plant exposed to light is equal in volume to the carbonic acid decomposed, so that apparently the whole of the oxygen contained in the carbonic acid is returned to the atmosphere; the reaction is, however, really more complicated, as water is probably decomposed at the same time as the carbonic acid.

The exact nature of the reaction which takes place when carbonic acid is decomposed in the chlorophyll cells is still unknown. Starch, composed of carbon and the elements of water ($C_6H_{10}O_5$), is undoubtedly among the earliest products. Starch being an insoluble substance is converted into sugar (glucose) for the nourishment of distant parts of the plant, to which it is conveyed by the movement of the sap. In parts where growth is taking place, and new cells are being formed, the sugar of the sap is converted into cellulose, the substance which forms the cell walls, and of which the whole structure of the plant primarily consists. The conversion of starch into sugar and cellulose presents no chemical difficulties, as all these substances are carbo-hydrates, that is they are composed of carbon and the elements of water.

The formation of albuminoids in the plant is not at present understood; we can only say that they are constituted out of the carbo-hydrates and some of the simple nitrogenous substances, most probably amides, present in the sap.

The vegetable acids in a plant are probably formed by oxidation; most likely by the oxidation of some of the carbo-hydrates.

The fatty matter of a plant may be formed from carbo-hydrates; or possibly from the splitting up of albuminoids.

We have just referred to oxidation as taking place in the plant. This is always going on in the interior during life, and as a result the plant is continually consuming a small quantity of oxygen, and giving out a small quantity of carbonic acid, an operation precisely similar to animal respiration. This action is not readily perceived during the day-time, being hidden by the opposite action of the chlorophyll cells, which absorb carbonic acid and evolve oxygen. If a plant is placed in darkness the respiratory action becomes manifest. The oxidation of matters already formed is an important means for the production of new bodies.

The decomposition of carbonic acid by green plants during daylight is of the utmost importance in maintaining an atmosphere suitable for the respiration of animals. An animal in breathing inspires atmospheric air; it expires air in which a part of the oxygen has been replaced by carbonic acid; the result of animal life is thus to accumulate carbonic acid in the atmosphere. Such accumulation would be injurious to health, but is prevented by the growth of plants. It has been calculated that an acre of forest, producing annually 5755 lb. of dry matter, will consume the carbonic acid produced by the respiration of 15.4 men.

Besides carbonic acid, plants are apparently capable of absorbing a small quantity of ammonia through their leaves. The uncombined nitrogen of the atmosphere is

not appropriated by plants. When rain occurs after severe drought water may be taken up to some extent through the leaf.

Plants which have no chlorophyll cells, and possess consequently no green colour, do not decompose carbonic acid. We have familiar examples of such plants in the broomrape and dodder of our clover fields, and in the common fungi. The broomrape and dodder are fed by the juices of the plant on which they live as parasites. The fungi derive their carbon from the decayed vegetable matter in the soil.

Another important function of leaves consists in the transpiration of water. This transpiration takes place through small openings in the under side of the leaves, known as stomata, which have the property of closing in dry air and opening in moist. Transpiration takes place only in light; it will occur abundantly, even in an atmosphere saturated with water, if the plant be only exposed to sunshine. A small amount of general evaporation, distinct from transpiration proper, may occur in darkness. The amount of water evaporated from the surface of a growing plant is very large; land that has borne a crop is always much drier than a bare fallow.

The results of transpiration to the plant are most important, the evaporation of water from the leaves being a principal cause of the rise of the sap, and the consequent drawing up of water from the soil containing plant food in solution.

Function of the Roots.—The roots of a plant are the organs by which it absorbs water from the soil, and with this water a variety of food elements are introduced.

The roots take up apparently all the diffusible substances (those capable of passing through a membrane) which are present in the water which they draw from the soil. The plant may thus receive a number of substances not actually required for its nutrition.

The feeding power of roots is not, however, confined to the taking up of ready-formed solutions, they are also capable of attacking some of the solid ingredients of the soil, which they render soluble and then appropriate. This important action of roots exists in different degrees with different plants. The action takes place only at the points of contact between the rootlets and the particles of the soil, and is brought about by the acid sap which the roots contain. This action of roots probably plays an important part in the supply of phosphoric acid and potash to the plant, as these substances, especially the former of them, exist in the soil in difficultly soluble forms, and are rarely found in solution in the water present in soils.

Besides furnishing the plant with its ash constituents, the root has the important function of supplying nitrogen; this is nearly always taken up in the form of nitrates. A plant is capable of making use of nitrogen in the form of nitric acid or ammonia; it also, according to several experimenters, is able to assimilate nitrogen when in the form of urea, uric and hippuric acids, and several other amide bodies. The facility, however, with which ammonia, and other nitrogenous substances, are converted into nitric acid in the soil is so great that nitrates become by far the most important source of nitrogen at a plant's disposal. Most plants are unable to assimilate the nitrogenous humus contained in soil.

The very weak solutions taken up by the roots are

concentrated in the upper parts of the plant, the water being rapidly evaporated by the leaves, as already mentioned. The essential ash constituents are employed in the formation of new tissues. The non-essential ash constituents which have been taken up by the roots are partly disposed of in a solid form, as a permanent incrustation of the older tissues. The soluble salts which are not thus disposed of, at first accumulate in the sap, and are probably more or less removed from the surface of the leaves and stem by the washing effect of rain.

The deposition of silica upon the external tissues of wheat, barley, and other graminaceous plants is a familiar example of the excretion of a non-essential ash constituent. Silica is also abundant in the old leaves, and in the outer bark of many trees, and is commonly found as an incrusting constituent of old tissues. Insoluble calcium salts, frequently the oxalate, are also deposited as incrusting matters in old tissues. These incrustations are indirectly of service to the plant, as they tend to harden the tissues and thus protect them from injury.

Soluble non-essential ash constituents, as chloride of sodium, are found abundantly in the succulent parts of plants when such ash constituents have been present in the soil. They generally diminish in quantity as the plant matures, and are never stored up in the seed.

The amount and composition of the ash of succulent plants, as meadow grass, clover, and mangel, is greatly influenced by the character of the soil, and the manure applied. The ash of a seed, on the other hand, is very constant in composition, resulting from the selective powers of the plant.

Of the particular action of the ash constituents within

the plant little is known. Phosphoric acid and potash are undoubtedly the most important of the ash constituents; they are always found concentrated in those parts of the plant where cell growth is most active, as, for instance, in the layer (cambium) between the wood and bark of a tree, and are abundantly stored up in the seed.

Silica was long supposed to be an essential constituent of wheat, barley, and other similar plants, and to be the ingredient on which the stiffness of their straw chiefly depended. It has been shown, however, that maize may be successfully grown without any supply of silica, and with no perceptible difference as to the stiffness of the stem. The grass growing on peat bogs contains scarcely any silica, though silica is abundant in ordinary hay.

Germination.—The seed is a storehouse of concentrated plant food, intended to nourish the germ till the root and leaf are developed. In the seeds of the cereals, and of many other plants, the chief ingredient is starch. Another class of seeds, of which linseed and mustard-seed are examples, contain no starch, but in its place a large quantity of fat. A seed generally contains a considerable amount of albuminoids; its ash is rich in phosphoric acid and potash.

For germination to take place, moisture, oxygen, and a suitable temperature are necessary. Under these conditions the seed swells, oxygen is absorbed, a part of the carbonaceous ingredients is oxidised, heat is developed, and carbonic acid evolved. During these changes the solid ingredients of the seed gradually become soluble; the starch and fat are converted into sugar; the albuminoids are converted into amides—as for instance asparagine, probably also into peptones. With this supply of

soluble food the radicle and plumule are nourished ; they rapidly increase in size, emerge through the coats of the seed, and, if the external conditions are suitable, soon commence their separate functions as root and leaf. The process of germination may be easily studied in the ordinary operation of malting barley.

Seeds buried too deeply in the soil may not germinate for lack of oxygen. Or if germination takes place the plumule may fail to reach the surface, the store of food in the seed being exhausted before the layer of soil is penetrated, and daylight reached. The smaller the seed, the less, as a rule, should be the depth of earth with which it is covered.

Plant Development.—The development of the plant after germination follows a regular course. With an annual, which produces seed and dies during the first season, we have first a great development of root and leaf, which collect and prepare materials for growth ; next comes the formation of a flower stem ; and lastly, the production of flower and seed; after which the plant dies.

The materials furnished by the root preponderate in the young plant ; but as the plant matures, the proportion of carbon compounds derived from the action of the leaves steadily increases. A cereal crop contains at the time of full bloom all the nitrogen and potash which is found in the mature crop ; the assimilation of phosphoric acid continues somewhat later ; the increase of carbon and silica proceeds as long as the plant is in a green state.

When seed formation begins an exhaustion of the other parts of the plant sets in, starch, albuminoids, phosphoric acid and potash being transferred from the root, leaf, and

stem, and stored up in the seed. If the season is a good one, and the development of the seed fully accomplished, the straw of the crop is left very thoroughly exhausted; while in a bad season it will retain far more of the materials acquired during growth. For the same reason straw cut while the crop is still green is far more nutritive than when perfect ripeness has been attained.

With a biennial or perennial crop the case is somewhat different. The first development of root and leaf is the same as in an annual; but towards the end of summer there is a storing up of concentrated plant food in the root or stem to serve for the commencement of growth in the following spring. In a biennial root crop, the turnip for instance, the root attains a great size in autumn, the leaves dying after transferring to the root their most important constituents. The next season the root throws up a flower stem, and the store of matter accumulated during the preceding autumn is consumed in the production of seed. With the production of seed the root is exhausted and the plant dies.

In trees plant food is stored up at the end of summer in the pith, the pith rays, and in the layer between the wood and bark. The leaves which fall in autumn have lost nearly all their starch, albuminoids, phosphoric acid and potash, these having been transferred to the stem. By the action of the sun in spring-time the new buds swell, the sap rises, the starch and other matters deposited in the wood during the previous autumn are re-dissolved, and employed at once for the production of new growths. The sugar found in maple sap during spring results from the transformation of starch stored up in the preceding autumn.

CHAPTER II.

THE SOURCES OF PLANT FOOD.

The Atmosphere.—The carbonic acid, ammonia, and nitric acid which it supplies—The quantity of combined nitrogen and chlorides contained in rain. *The Soil.*—Its origin—Properties of sand, clay, calcareous matter, and humus; their relation to water and heat—The plant food contained in soil, its quantity, and condition—Losses by drainage—The absorptive power of soils—Influence of tillage, drainage, and burning.

The Atmosphere.—We have already stated that the whole of the carbon of plants is obtained from the carbonic acid present in the atmosphere; 10,000 volumes of air contain about $3\frac{1}{2}$ volumes of carbonic acid, or about 1 lb. of carbon in 3500 cubic yards of air. This small amount is made sufficient by the action of winds, which bring an enormous quantity of air in contact with both soil and plant.

The atmosphere also contains a very small and variable quantity of ammonia. Schlœsing found from 1 lb. in 6,000,000 cubic yards, to 1 lb. in 119,000,000 cubic yards. The quantity is greatest, according to the same experimenter, in warm southerly winds. The ammonia of the air is directly absorbed by plants to a very small extent, it is rendered available chiefly through absorption by the soil, and by means of rain, which brings it in solution to the earth.

The atmosphere also furnishes a small amount of nitric acid. The nitrogen and oxygen of the atmosphere combine under the influence of electric discharges, nitrous acid being formed; this is converted into nitric acid by the action of ozone, or peroxide of hydrogen. This formation of nitric acid in the atmosphere is the only original source of combined nitrogen on our globe the existence of which has been placed beyond dispute. Nitric acid may also be formed in the atmosphere by the oxidation of ammonia by ozone and peroxide of hydrogen.

The total amount of nitrogen, in the form of ammonia and nitric acid, annually carried to the soil by rain, varies in different years and places. The average of many experiments on the continent gives 10.23 lb. of nitrogen per acre. The average of two years' experiments at Rothamsted gave 7.29 lb. The continental average is probably rather above the truth for the open country, many of the determinations having been made near towns.

Rain also furnishes small quantities of alkaline chlorides, especially in the neighbourhood of the sea; sulphates are also present. At Cirencester the chlorides in the rain are on an average equal to about 53 lb. of common salt per acre per annum; at Rothamsted in Hertfordshire the quantity is about 22 lb.

The Soil.—All soils have been produced by the disintegration of rocks, generally through the prolonged action of water, air, and frost. The character of a soil largely depends on the character of the rock from which it has been derived. Primitive and igneous rocks yield soils rich in potash; fossiliferous rocks produce soils rich in phosphoric acid. The principal ingredients of soils are

sand, clay, carbonate of calcium, and humus; as each of these preponderate the soil is said to be sandy, clayey, calcareous, or peaty.

Sand is either composed of pure quartz (silica), or consists of fragments of more complex minerals—mica, for example. When the former is the case, the sand will supply no plant food; but in the latter case the gradual decomposition of the mineral will slowly increase the ash constituents available for the plant.

Clay is a silicate of aluminium, produced by the decomposition of felspar and other silicates; if absolutely pure it would furnish nothing to the plant; it always, however, contains some potash, and frequently a considerable quantity. Clay has the important property of absorbing and retaining phosphoric acid, ammonia, potash, lime, and other substances necessary for plant nutrition.

The calcareous matter of soils supplies lime to the plant; limestone also generally contains phosphoric acid. Carbonate of calcium is beneficial to the soil in many ways. It preserves the particles of clay in a separate coagulated condition, thus making heavy soils friable and pervious to water. It enables clay to exercise its absorbent power on various salts, which would otherwise escape its action. It also promotes the decomposition of vegetable matter, and the formation of nitrates in the soil. The presence of some salifiable base is essential for the performance of the chemical operations belonging to a fertile soil; the salifiable bases usually present are either carbonate of calcium, or the alkalis derived from the decomposition of silicates.

The humus, or decayed vegetable matter of soils, has its origin in the dead roots, leaves, &c., of a previous vegeta-

tion. It is the principal nitrogenous ingredient of soils. A black soil, rich in humus, is sure to be also rich in nitrogen; a soil destitute of humus will contain scarcely any nitrogen. The fertility of virgin soils is largely due to the nitrogenous humus which they contain.

Of all soil ingredients sand has the least, and humus the greatest capacity for retaining water. Light sandy soils thus suffer most from drought, while applications of farmyard manure, or the ploughing in of green crops, increase the water-holding power of a soil by increasing the proportion of humus. The capillary power of soil, by which water is raised from the subsoil to the surface in dry weather, is least in open sandy soils composed of coarse particles, and greatest in the case of loam or clay.

Dark-coloured soils absorb the greatest amount of heat from the sun's rays, and light-coloured soils least. The presence of humus is thus favourable to soil warmth. Quartz sand is an excellent conductor of heat; chalk is a bad conductor. A soil rich in sand will thus be warmed or cooled more rapidly, and to a greater depth than a soil containing but little sand. Water has a very considerable effect in cooling a soil, partly from its high specific heat, and partly from the immense consumption of heat during its evaporation. A wet soil is always colder than a dry one. The drainage of wet land will thus result in a greater warmth of the surface soil, and consequently an earlier growth in spring.

The proportion of plant food present in soils is very small, even when the soil is extremely fertile. The surface soil (first 9 inches) of a pasture may contain when dry 0.25 of nitrogen per cent., while soil of the same depth from a good arable field may yield 0.15 per cent., and a clay

sub-soil 0.05 per cent. A good surface soil may contain 0.20 per cent. of phosphoric acid, or not unfrequently a smaller quantity. Potash varies much, rising to 1.0 per cent. or more in some clay soils, but being generally much smaller.

The weight of soil on an acre of land is, however, so enormous, that small proportions of plant food may amount to very considerable quantities. Nine inches' depth of arable soil (clay or loam) will weigh, when perfectly dry, about 3,000,000 or 3,500,000 lb. A pasture soil will be lighter, the first 9 inches weighing when dried and the roots removed about 2,250,000 lb. Supposing, therefore, a dry soil to contain 0.10 per cent. of nitrogen, phosphoric acid, or potash, the quantity in 9 inches of soil will be from 2250 lb. to 3500 lb. per acre.

A large part of the elements of plant food contained in soils is present in such a condition that plants are unable to make use of it. A soil may contain many thousand pounds of phosphoric acid or of nitrogen, and yet be in a poor condition; while a small dressing of readily available food, as superphosphate or nitrate of sodium, may greatly increase the fertility.

The nitrogen contained in humus is not in a condition to serve as a general plant food; cereal crops are apparently unable to appropriate it; leguminous crops, however, possibly assimilate some humic matters. By the action of a minute *Bacterium* present in all soils, humus and ammonia are oxidised, and their nitrogen converted into nitric acid. Nitrification only takes place in moist soil, sufficiently porous to admit air. It is also necessary that some base should be present with which the nitric acid may combine: this condition is usually fulfilled by the presence of carbonate of calcium. Nitrification is most

active at summer temperatures; it ceases apparently near the freezing point.

The fragments of rock present in soil, as stones, gravel, and sand, are as a rule of little value to a plant, the elements of plant food which they contain being in too insoluble a condition to be attacked by the roots. These fragments of rock may however be slowly decomposed by the mechanical action of frost, and by the chemical action of water, and their contents thus gradually made available to the plant. The solvent power of the water in a soil is greatly increased by the carbonic acid, and perhaps also by the humic acid it holds in solution. Water containing carbonate of calcium in solution is especially capable of attacking silicates.

If water is allowed to drain through a soil it carries with it a part of the readily soluble matter which a soil contains. The substances chiefly removed by the water will be the nitrates, chlorides, and sulphates of calcium and sodium. When heavy rain falls these substances are washed into the subsoil, and partly escape by the nearest outfall into the springs, brooks, and rivers. The loss of nitrates from highly manured land during a wet season is very considerable. When dry weather sets in evaporation takes place at the surface of the soil, the water of the subsoil is slowly brought again to the surface by capillary attraction, and the salts it contains are concentrated once more in the upper soil, forming in some rare instances a white crust of salt upon the surface. Capillary attraction has little influence in the case of sandy soils.

Of these readily soluble salts the nitrates are of the greatest importance as plant food. The quantity of nitrates in a surface soil will vary greatly, depending on

the richness of the soil in nitrogen, the previous conditions as to temperature and moisture, the extent of recent washing by rain, and on whether the soil is or is not under crop. Where a crop is growing the nitrates will be kept nearer the surface, the evaporation of water from a growing crop being far greater than from a bare soil. The nitrates will also be constantly taken up by the roots, and employed as plant food. The loss of nitrates by drainage is thus far less when the land is under crop than in the case of a bare fallow.

Phosphoric acid, potash, and ammonia are very rarely found in drainage water. If a solution containing phosphoric acid, potash, or ammonia is poured on a sufficiently large quantity of fertile soil, the water which filters through will be found destitute of these substances. This retentive power of soil for phosphoric acid, potash, &c., is of the utmost importance in agriculture. The action is a complex one. All salts are doubtless retained to some extent by soil through mere mechanical adhesion; salts, thus feebly retained, as nitrates and chlorides, can be easily removed by washing with water. Other substances are, on the contrary, retained by chemical affinity; these are not removed by washing, or but to a small extent. The ingredients of the soil which exercise a chemical retentive power are the hydrates of ferric oxide and alumina, the hydrous silicates of aluminium, and humus.

Ferric oxide is a common ingredient of soils; to it the red colour of many soils is owing. To the presence of ferric oxide the retention of phosphoric acid is chiefly due, an insoluble basic phosphate of iron being produced. Alumina acts in the same manner. Ferric oxide and alumina have also a retentive power for ammonia and

potash, but the compounds formed are more or less decomposed by water. To the hydrous silicates the permanent retention of potash and other bases is probably chiefly due. Humus has a great absorbent power for ammonia. Other bases, as magnesia and lime, are also retained by soil, but in a less powerful manner than are potash and ammonia.

Soils destitute of carbonate of calcium take up very little potash or ammonia when these are applied as salts of powerful acids, as for instance, the chlorides, nitrates, and sulphates. When carbonate of calcium is present the potassium or ammonium salt is decomposed, the base is retained by the soil, while the acid escapes into the drainage-water united with calcium. The addition of carbonate of calcium may thus greatly increase the retentive power of a soil for bases.

The fertility of a soil is nearly connected with its power of retaining plant food. Sandy soils, from their small chemical retentive power, and free drainage, are of small natural fertility, and dependent on immediate supplies of manure.

There can be little doubt that the plant food contained in soil which is capable of being taken up by roots, exists either in solution, or in the states of combination just referred to—that is in union with ferric oxide, hydrous silicates, and humus. Different crops have very different powers of attacking these various forms of plant food.

The operations of tillage and drainage serve in several ways to increase the amount of plant food which is at the disposal of a crop.

By tillage the surface soil is kept in an open porous condition, favourable for the distribution of roots. By

this means also capillary attraction is diminished, and the land consequently suffers less from drought; the water-holding power of the surface soil is also increased. A more important result of tillage is that the soil is thoroughly exposed to the influence of the air. Soils containing humus or clay will absorb ammonia from the atmosphere, and thus increase their store of nitrogen. The organic remains of former crops and manuring are also oxidised, the nitrogen being converted into nitric acid. The rocky fragments which a soil contains, as fragments of silicates or limestone, will at the same time be more or less disintegrated by the combined action of water and air, assisted by the carbonic and humic acids arising from the oxidation of vegetable matter, and a portion of the insoluble plant food be thus brought into a state suited for assimilation by the roots of crops. In winter time the disintegration of the various ingredients of the soil is greatly assisted by frost. Water in freezing expands, and thus rends asunder the substance frozen. Of the various results brought about by tillage, the increased production of nitrates must be ranked among the most important.

By drainage the various chemical actions we have just mentioned are carried down to a greater or less extent into the subsoil, for as the water level is lowered the air enters from above to fill the cavities in the soil. By drainage also the depth to which roots will penetrate is increased, for roots will not grow in the absence of oxygen, and rot as soon as they reach a permanent water level. In a water-logged soil deoxidation is active, the nitrates present are destroyed, a part of the nitrogen being evolved as gas; the soil may thus suffer a considerable loss of plant food.

Burning is occasionally resorted to as a means of increasing the available plant food, and improving the texture of a heavy soil. The soil is burnt in heaps, which are then spread over the land. If the soil contains limestone it is easy to see that the phosphates of the limestone may become more available by the complete disintegration which attends the conversion into lime. The lime will also attack the silicates of the soil at a high temperature, and liberate a part of the potash from its insoluble combinations. To produce the best results it is essential that the burning should take place at a low temperature. This treatment by burning is a very extreme one, and can be recommended only in few cases; it must always be attended with an entire loss of the nitrogen in the soil burnt. The ploughing in of burnt clay is of use in improving the texture of heavy land.

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CHAPTER III.

MANURES.

Difference between natural vegetation and agriculture—necessity for manuring. *Farmyard Manure.*—Circumstances which influence its character ; its average composition ; slowness of its effect—Seaweed similar to farmyard manure—*Guano—Sulphate of Ammonium—Nitrate of Sodium—Soot, Dried Blood, and Woollen Refuse—Bones—Ground Phosphates—Superphosphate—Gypsum—Lime, Chalk, and Marl—Potassium Salts—Common Salt—Application of Manure*—Importance of thorough distribution—Best time for application—The return made by the crop.

In the natural vegetation of a forest or prairie the soil suffers no diminution of plant food. The elements taken from the soil are returned to it on the decay of the plants which the soil has nourished, or on the death of the animals which have fed on these plants. Under these circumstances the surface soil becomes rich in carbon and nitrogen, the quantity contributed by the atmosphere exceeding all losses. The surface soil also becomes rich in the ash constituents of plants, these being collected from the subsoil by the roots, and left at the surface on the decay of the plant. A virgin soil thus generally contains an abundance of plant food, and will produce large crops without manure.

In human agriculture, on the other hand, both vegetable and animal produce are consumed off the land

that has reared them. Provision must therefore be made, sooner or later, to return to the land a part at least of the plant food removed from it, if permanent fertility is to be maintained. Hence the necessity for manuring.

The most complete return to the land would be accomplished by manuring it with the excrements of the men and animals consuming the crops. This is partially done by the application of farmyard manure; but the congregation of men in cities, and the difficulty of employing sewage with profit, prevent this plan being thoroughly carried out. The farmer is thus generally obliged to purchase manures for the land in exchange for the crops and stock sold off it.

On very poor soils it is necessary to make a very complete return of all the elements of plant food removed by the crops, but in most soils there is an abundance of some one or more of these elements, and a partial manuring will consequently suffice. With high farming the contributions to the soil may be in excess of the exports, and the land consequently increase in fertility. The nature of the exhaustion resulting from the growth of particular crops, and the economic application of manure to meet their special requirements, will be considered in Chapter IV. The losses which a farm sustains by the sale of animal products will be treated of in the section on "The Constituents of Animals," page 61.

Farmyard Manure consists of the liquid and solid excrements of the farm stock, plus the straw employed as litter. Its composition will vary according to the character of the animals contributing to it, the quality of their

food, and the nature and proportion of the litter. The composition of the manure will also depend a good deal upon the method in which it has been prepared.

In the case of an adult animal, neither gaining nor losing weight—a working horse for instance—the excrements will contain the same quantity of nitrogen and ash constituents as was present in the food consumed. If however the animal is increasing in size, is producing young, or furnishing milk or wool, the nitrogen and ash constituents in the excrements will be less than those contained in the food, the difference appearing as animal increase. The manure from animals of this class will therefore be poorer than that obtained from the former class, supposing the same food given to each. We must not expect valuable manure from a cow in full milk, or from a rapidly growing pig.

The character of the food will affect the quality of the manure even more than the character of the animal. A diet of maize and straw chaff can yield only a poor manure, because these foods contain very little nitrogen or phosphates. A diet including a liberal amount of oil-cake or beans will, on the other hand, yield a valuable manure, these foods being rich in nitrogen and ash constituents. A common mode of increasing the supply of manure on a farm is by the consumption of purchased food by the stock. This part of the subject will be more fully discussed in Chapter IX.

The treatment of the manure is also most important. A large proportion of the nitrogen is voided in the form of urine, and generally the richer the diet the higher will this proportion be. If, therefore, the manure is washed by rain, and the washings are allowed to drain away, serious

loss will occur. Hence the superiority of box manure to that made in an open yard.

It must also be recollected that the urea, which forms the chief nitrogenous ingredient of urine, is speedily changed by fermentation into carbonate of ammonium; as this is a volatile substance, a loss of a part of the nitrogen may easily occur, especially if an insufficient amount of litter is employed.

Farmyard manure rapidly undergoes fermentation. If placed in a heap the mass gets sensibly hot, and a large quantity of carbonic acid is given off. When the fermentation occurs in a place protected from rain carbonaceous matter is destroyed, but little loss of nitrogen takes place. Rotten manure, when well made, is more concentrated than the fresh, having diminished in weight during fermentation, with but little loss of valuable constituents. Some of the constituents have also become more soluble.

Farmyard manure will contain from 65 to 80 per cent. of water. The nitrogen may be 0.40 to 0.65 per cent., or higher, if produced by highly fed animals. The ash constituents will be 2.5 to 3.0 per cent., exclusive of the sand and earth always present. Of these ash constituents 0.4 to 0.7 will be potash; and 0.2 to 0.4 phosphoric acid. One ton of farmyard manure will thus supply 9—15 lb. of nitrogen, a similar amount of potash, and 4—9 lb. of phosphoric acid.

Farmyard manure is a "general" manure; that is it supplies all the essential elements of plant food. The immediate return from an application of farmyard manure is much less than from the same amount of plant food applied in artificial manures. The effect of farmyard

manure is spread over a considerable number of years, its nitrogen being chiefly present not as ammonia but in the form of carbonaceous compounds, which decompose but slowly in the soil.

Seaweed when fresh is, on the whole, similar in value to farmyard manure. It becomes more valuable as it loses water.

Guano.—This manure consists chiefly of the dried excrements of sea fowl. When guano has been deposited in the absence of rain it contains a large amount both of nitrogenous matter and phosphates. If exposed to rain the original nitrogenous matter is decomposed, and the nitrogen volatilised in the form of carbonate of ammonium; the guano remaining is then almost purely phosphatic. Ichaboe guano, for example, is a recent deposit, containing about 12 per cent. of nitrogen, and 12 per cent. of phosphoric acid; while Mejillones guano is a phosphatic guano, containing 0.9 per cent. of nitrogen, and 32.5 per cent. of phosphoric acid. From its great variation in composition guano should always be purchased on analysis.

In a nitrogenous guano the nitrogen is chiefly present as uric acid, and as ammonium salts. The strong smell of a damp guano is due to carbonate of ammonium. The phosphoric acid exists principally in the form of phosphate of calcium, but in nitrogenous guanos a small part exists as phosphate of ammonium, a salt readily soluble in water. Guano which has not suffered by washing may contain 3 to 4 per cent. of potash.

Nitrogenous guano is a highly concentrated manure, and may be employed with excellent effect for corn crops, potatos, and roots. Phosphatic guanos may be employed

for turnips, but such guanos are more usually converted into superphosphate before they are applied to the land.

Sulphate of Ammonium.—This substance is prepared from the ammoniacal products of gas works; in its crystallised form it is the most highly nitrogenous of all the manures at a farmer's disposal, containing about 20 per cent. of nitrogen.

It should be ascertained in every case that the manure is free from sulphocyanate of ammonium, as this substance is very injurious to plants. If sulphocyanates are present a solution of the salt will become blood-red on the addition of ferric chloride.

Sulphate of ammonium is a "special" manure, valuable solely for its nitrogen. It is a powerful manure for corn crops, for which it is best employed in conjunction with superphosphate.

Nitrate of Sodium.—An enormous deposit of the crude salt, containing much chloride of sodium, is found in Peru. The nitrate sent to this country has been purified by crystallisation; it will contain about 15.6 per cent. of nitrogen. The most usual impurity is common salt.

This manure, like the preceding, is valuable solely for its nitrogen. It is an excellent manure for all crops requiring artificial supplies of nitrogen, especially corn crops and mangels. For corn crops it is best employed together with superphosphate. Nitrate of sodium should not be mixed with a damp superphosphate, else nitric acid may be lost. It is best to mix the two immediately before use; or the superphosphate may be sown with the corn, and the nitrate applied afterwards as a top dressing.

Nitrate of sodium is especially suited for clay land. It is quicker in its action than any other nitrogenous manure, and is therefore the best manure to employ when a late dressing has to be given.

Soot, Dried Blood, and Woollen Refuse are all purely nitrogenous manures. Soot owes its value to the presence of a small and variable quantity of ammonium salts. Dried blood is an excellent manure, containing 10 to 13 per cent. of nitrogen. Shoddy, and other forms of wool and hair are very variable in composition, owing to admixture of dirt, grease, and other foreign matter; the nitrogen they contain will range from about 5 to 10 per cent.

The nitrogen of blood, wool, and hair, is not in a form suitable as plant food. Blood readily decomposes in the soil, yielding ammonia and nitric acid. Wool and hair decompose much more slowly, and their effect is spread over many years.

Soot is generally employed as a top dressing for spring corn. Dried blood is an excellent manure for wheat. Wool and hair are chiefly used for hops.

Bones.—These are largely employed as manure; the fat is usually first extracted by steaming. Commercial bones contain about 3.6 per cent. of nitrogen, and 23 per cent. of phosphoric acid, existing as phosphate of calcium. Bones that have been boiled to extract the gelatin contain much less nitrogen, but a larger proportion of phosphates.

Bones decompose but slowly in the soil, especially on heavy land; their effect is thus spread over several years. The finer the bones have been ground the more immediate

is their effect. Bones are usually employed for pasture, and for turnips.

Ground Phosphates.—Some phosphates when finely ground may on certain soils be successfully employed as manure without previous conversion into superphosphate. The phosphates most suitable for this purpose are phosphatic guanos, bone-ash, and South Carolina phosphate. The soils most suitable for such manures are those rich in humus, and poor in carbonate of calcium; these being the conditions (presence of humic and free carbonic acid) most favourable to the solution of phosphate of calcium. Pasture soils are especially suitable for such treatment. The solution of the ground phosphate may be facilitated by forming it into a compost with farmyard manure before its application, or by employing with it sulphate of ammonium. The phosphate should be employed in very fine powder.

Superphosphate.—An abundance of mineral phosphates (phosphates of calcium) occur in nature; many of these are so little soluble that their effect as manure is but small; by treating them with sulphuric acid the sparingly soluble tricalcic phosphate is converted into the readily soluble monocalcic phosphate, sulphate of calcium being at the same time produced. Superphosphate is thus a mixture of monocalcic phosphate, and generally some free phosphoric acid, with gypsum, and various impurities (as sand and compounds of iron and aluminium), derived from the original mineral. A superphosphate will always contain more or less of undissolved phosphate; this amount will be more considerable if the manure is badly

made, or if the original mineral contained much ferric oxide or alumina.

The value of a superphosphate chiefly depends on the percentage of "soluble phosphate" present. By this term analysts do not mean monocalcic phosphate, but the quantity of tricalcic phosphate rendered soluble.

The best mineral phosphate found in England is Cambridge coprolite. This is largely used for making superphosphate. Other coprolites are also employed, but they are less suitable. Immense quantities of mineral phosphates are imported, principally from South Carolina, Spain, Bordeaux, and Canada, besides considerable quantities of phosphatic guano.

The superphosphates richest in soluble phosphate (40 to 45 per cent.) are prepared from phosphatic guanos. Bone ash, and some phosphorites, also yield high quality manures. The great bulk of our superphosphates is at present prepared from Carolina phosphate or coprolite; such manure will contain 23 to 27 per cent. of soluble phosphate.

Superphosphates form the basis of almost all manufactured manures. By using bones, or by adding shoddy or crude ammonium salts, turnip manures are produced containing a small amount of nitrogen. By mixing with the superphosphate a larger amount of ammonium salts, or nitrate of sodium, the articles sold as *corn, grass, mangel,* and *potato manures* are prepared. Superphosphate made largely from bones is known as *dissolved bones.*

When superphosphate is applied to a soil containing carbonate of calcium, the soluble phosphate is speedily precipitated, but in a form easily taken up by the roots of plants. In most cases the phosphoric acid is finally con-

verted into basic phosphate of iron, a substance attacked with difficulty by plants.

Superphosphates are naturally more speedy in their effect than manures consisting of undissolved phosphate. A small quantity of phosphoric acid applied as superphosphate will have as great an effect as a considerable quantity applied as bones or ground phosphate.

Superphosphate is chiefly employed for turnips, for which it is invaluable; it is also of considerable use for corn crops, especially barley. Its use tends to early maturity in the crop.

Gypsum.—This manure is one of limited value. It is composed of calcium and sulphuric acid, and is most suitable for crops, such as clover and turnips, which require a considerable amount of sulphur. As superphosphate always contains much gypsum, special applications of gypsum will be unnecessary where superphosphate is employed.

Lime, Chalk, and Marl are frequently manures of the greatest importance. On soils naturally destitute of lime, as is the case with many clays and sandstones, these manures will supply an indispensable element of plant food. Some marls will also supply a notable quantity of phosphoric acid. In most cases, however, the beneficial influence of these manures is due to the chemical actions which lime performs in the soil; the chief of these have been already glanced at under the head of "Soil," (see page 15).

Burnt lime is much more powerful in its action on vegetable matter than chalk or marl; it should be used with

discrimination, lest the humus of the soil be unduly diminished. Heavy clays, or soils rich in humus, are those most benefited by burnt lime. In reclaiming peat bogs lime is of the highest value. The acid humic matter of the peat is neutralised by the lime, and the nitrogen held in combination is converted into ammonia and nitric acid, and thus made available to a crop.

The general effect of lime is to render available the plant food already in the soil, without itself supplying any significant amount; liming cannot, therefore, be successfully repeated except at considerable intervals.

Potassium Salts.—These salts are now obtained from Stassfurt and Leopoldshall in large quantities; they form a thick deposit overlying an enormous mass of rock salt. The commonest potassium salt employed as manure is kainit; it consists of chloride of potassium, sulphate of magnesium, and water, with frequently chloride of magnesium and common salt in addition. Kainit will contain 13 to 14 per cent. of potash. Calcined kainit contains less water, and some magnesia in place of the chloride of magnesium; it will contain 15 to 17 per cent. of potash.

Wood ashes may also be employed as a potash manure; they will contain between 5 and 15 per cent. of potash. The ash of young boughs is richer than that from full-sized timber.

Potash manures produce their greatest effect on pasture; clover and turnips may also be benefited by their use. Many soils are naturally well furnished with potash, on these soils potash manures are almost without effect.

Common Salt.— Chloride of sodium supplies no essential

ingredient of plant food. The little value which salt possesses as a manure is probably due to its action in the soil, where it may help to set free more important constituents.

Application of Manures.—A manure can be efficacious only when its constituents are brought into contact with the roots of the crop. To obtain this contact to the fullest extent the manure must be thoroughly and evenly distributed throughout the depth of soil mainly occupied by the roots. Soluble manures—as nitrate of sodium, chloride of sodium, ammonium salts, potassium salts, and superphosphate—have the great advantage that they distribute themselves within the soil after the first heavy shower far more perfectly than can be done by any mode of sowing. When manure is especially required by the plant in its earliest stages—as superphosphate for turnips—it may be drilled with the seed ; but, as a rule, manure should be sown broadcast, and ploughed in or harrowed.

Top-dressing, that is sowing manure on the surface of land already under crop, should generally be confined to manures that are soluble, or the principal constituents of which easily become soluble in the soil. Nitrate of sodium is sown with advantage in this manner if showery weather can be depended on to distribute the manure in the soil. On pasture all manures are necessarily applied as top-dressings.

Whenever possible, manure should be reduced to a fine powder before application. Artificial manures, if distributed by hand, should first be made up to a considerable bulk by mixing with fine dry soil or ashes. Manures containing ammonia must not be mixed with alkaline ashes, else some of the ammonia will be lost.

Manures of little solubility, or those for which the soil has a great retentive power, may be applied to the land some time before the growing period of the crop. Diffusible manures, on the other hand, should be applied only when the crop is ready to make use of them, else serious loss may occur from drainage. Farmyard manure, rape cake, and bones, and to some extent superphosphate and potassium salts, belong to the former class; while nitrates, and all manures containing ammonia, belong to the latter class. It was formerly supposed that the great retentive power of fertile soils for ammonia would effectually prevent any loss by drainage; we now know that ammonia is speedily converted into nitrates after mixing with the soil, and that these nitrates are readily washed out by heavy rain.

Following these principles, an autumn manuring for wheat may consist of farmyard manure, blood, or shoddy, with or without superphosphate; but dressings of guano, ammonium salts, or nitrate of sodium should be deferred till the spring. The question is, however, clearly one of climate, and with a dry winter climate ammonium salts or guano may be applied with advantage in the autumn.

On soils of open texture, and little retentive power, preference must often be given to manures of little solubility, in order to diminish the loss occasioned by heavy rain. Bulky organic manures, as farmyard manure or seaweed, are in such cases very suitable.

No dressing of manure is completely taken up by the crop to which it is applied, dressings larger than the actual requirements of the crop must therefore be applied to obtain a given result. Soluble and active manures

produce their principal effect at once, and are of little benefit to subsequent crops. Sparingly soluble manures, and those which must suffer decomposition in the soil before they are of service to the plant, as farmyard manure and bones, will on the contrary continue to produce an effect over many years. Farmers have a prejudice in favour of the latter class of manures, but it is clear that the quickest return for capital invested is afforded by the former class.

Nitrogen applied as ammonium salts or nitrates will give all its effect during the first year; 45 to 50 per cent. of the nitrogen applied in this form to wheat and barley is, according to Lawes and Gilbert, recovered on an average in the increase. In the case of farmyard manure, applied on the heavy land at Rothamsted to wheat and barley, only about 10 to 15 per cent. of the nitrogen was recovered in the increase, but the effect on the barley continued many years after the application of the manure ceased. It is evident that a small quantity of an active manure will accomplish the same work as a large quantity of one less active.

The residues of phosphatic and potassic manures are available for subsequent crops, but are distinctly less active than fresh applications of the same manures.

CHAPTER IV.

CROPS.

The dry matter, nitrogen, and ash constituents, in average crops. *Cereal Crops.*—Characteristic composition—Mode of feeding—Most suitable manuring. *Meadow Hay.*—Characteristic composition—Demand for ash constituents—Influence of manures on quantity and quality—Pasture especially suited for obtaining nitrogen from the atmosphere. *Leguminous Crops.*—Characteristic composition—Source of nitrogen obscure—Clover-sickness. *Root Crops.*—Characteristic composition—Differences in the nutrition of turnips, mangels, and potatos. *Forest Growth.*—Large production of dry matter for small consumption of ash constituents and nitrogen. *Adaptation of Manures to Crops.*—The feeding power of each crop must be taken into account—Economic distribution of manure in a rotation—The practical value of manures only known by experiments on each farm. *Influence of Climate and Season.*

To understand the chemistry of crops we must first inquire as to their composition. The following table gives the average composition of ordinary farm crops and of the annual produce of three kinds of forest. The quantities of carbon, hydrogen, and oxygen present are omitted, also some of the smaller ash constituents. By "pure ash" is understood the ash minus sand, charcoal, and carbonic acid.

The composition of grain, and of all seeds, is tolerably constant; but the composition of straw, leaves, roots, and tubers, will vary very considerably according to the character of the soil, manure, and season.

THE WEIGHT AND AVERAGE COMPOSITION OF ORDINARY CROPS IN POUNDS PER ACRE.

	Weight of crop.		Total pure ash.	Nitrogen.	Sulphur.	Potash.	Soda.	Lime.	Magnesia.	Phosphoric Acid.	Chlorine.	Silica.
	At Harvest.	Dry.										
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
WHEAT, grain, 30 bush. . .	1,800	1,530	31	33	2·7	9·7	0·9	1·0	3·7	14·3	0·2	0·5
„ straw	3,158	2,653	158	12	5·1	18·2	2·5	9·2	4·0	8·4	1·7	110·6
Total crop . . .	4,958	4,183	189	45	7·8	27·9	3·4	10·2	7·7	22·7	1·9	111·1
BARLEY, grain, 40 bush. . .	2,080	1,747	46	35	2·9	9·8	1·0	1·3	4·0	16·2	0·4	12·0
„ straw	2,447	2,080	100	12	3·2	21·6	4·2	8·5	2·5	4·4	3·2	51·5
Total crop . . .	4,527	3,827	146	47	6·1	31·4	5·2	9·8	6·5	20·6	3·6	63·5
OATS, grain, 45 bush. . . .	1,890	1,625	54	38	3·2	8·5	1·4	2·0	3·9	11·8	..	24·8
„ straw	2,835	2,353	140	14	4·8	29·6	5·9	9·8	5·3	7·1	5·5	69·3
Total crop . . .	4,725	3,978	194	52	8·0	38·1	7·3	11·8	9·2	18·9	5·5	94·1
MEADOW HAY, 1½ ton . . .	3,360	2,822	208	49	5·7	56·3	11·9	28·1	10·1	12·7	16·2	57·5
RED CLOVER HAY, 2 ton . .	4,480	3,763	255	102	9·4	87·4	4·1	86·1	30·9	25·1	9·4	6·8
BEANS, grain, 30 bush. . . .	1,920	1,613	57	77	4·4	23·0	0·8	2·9	3·8	22·3	1·5	0·8
„ straw „ . . .	2,240	1,848	130	22	4·9	58·1	4·9	30·2	10·3	9·2	18·1	6·9
Total crop . . .	4,160	3,461	187	99	9·3	81·1	5·7	33·1	14·1	31·5	19·6	7·7

TURNIPS, root, 17 ton	38,080	3,126	218	71	15·2	108·6	17·0	25·5	5·7	22·4	10·9	2·6
,, leaf ,,	11,424	1,531	146	49	5·7	40·2	7·5	48·5	3·8	10·7	11·2	5·1
Total crop	49,504	4,657	364	120	20·9	148·8	24·5	74·0	9·5	33·1	22·1	7·7
SWEDES, root, 14 ton	31,360	3,349	163	74	14·6	63·3	22·8	19·7	6·8	16·9	6·8	3·1
,, leaf ,,	4,704	706	75	28	3·2	16·4	9·2	22·7	2·4	4·8	8·3	3·6
Total crop	36,064	4,055	238	102	17·8*	79·7	32·0	42·4	9·2	21·7	15·1	6·7
MANGELS, root, 22 ton	49,280	5,628	410	96	4·9	191·1	75·4	24·2	19·7	34·0	40·6	16·4
,, leaf	18,233	1,654	280	51	9·1	71·4	65·2	29·1	27·2	15·1	49·8	9·2
Total crop	67,513	7,282	690	147	14·0	262·5	140·6	53·3	46·9	49·1	90·4	25·6
POTATOS, tubers, 6 ton	13,440	3,360	126	47	2·7	75·4	2·0	2·9	5·7	24·1	3·5	2·9
,, haulm *	4,274	954	50	20	2·1	1·1	2·0	22·7	12·4	2·7	1·9	2·1
Total crop	17,714	4,314	176	67	4·8	76·5	4·0	25·6	18·1	26·8	5·4	5·0
BEECH, wood	..	2,822	26	..	..	4·2	0·8	12·9	3·4	2·6	..	2·2
,, leaf litter	..	2,975	166	..	..	8·8	1·6	73·1	10·9	9·3	..	53·9
Total produce	..	5,797	192	..	..	13·0	2·4	86·0	14·3	11·9	..	56·1
SPRUCE FIR, wood	..	3,064	20	..	..	3·6	0·4	8·2	1·8	1·3	..	2·9
,, leaf litter	..	2,683	121	..	..	4·3	1·5	54·4	6·2	5·7	..	44·3
Total produce	..	5,747	141	..	..	7·9	1·9	62·6	8·0	7·0	..	47·2
SCOTCH PINE, wood	..	2,884	15	..	..	2·3	0·2	9·0	1·5	1·0	..	0·5
,, leaf litter	..	2,845	42	..	..	4·3	1·7	16·8	4·3	3·3	..	5·8
Total produce	..	5,729	57	..	..	6·6	1·9	25·8	5·8	4·3	..	6·3

* Calculated from a single analysis only.

Cereal Crops.—These contain much less nitrogen than either the leguminous or root crops; about three-quarters of the nitrogen is in the corn, and only one quarter in the straw. The amount of phosphoric acid is not very different from that found in other crops; this ingredient is, in fact, the most constant of all the constituents of crops; it is chiefly concentrated in the corn. Potash and lime are present in much smaller quantity than in other crops; they are chiefly concentrated in the straw.

The presence of a large amount of silica is characteristic of the cereal crops; they possess apparently a capacity for feeding on silicates not enjoyed by other crops. The base of the silicate is made use of by the plant, while the silica itself is excreted upon the surface of the leaves and straw. It has been shown that silica is by no means essential for the growth of cereals; they take it up freely, but can also do without it.

The autumn sown cereals (wheat and rye) have both deeper roots, and a longer period of growth, than the spring sown cereals, and are better able than the latter to supply themselves with the necessary ash constituents from the soil. Barley possesses a considerable development of root near the surface, and is apparently more capable of obtaining nitrogen from the soil than wheat.

Cereal crops derive their nitrogen almost exclusively from nitrates; the form in which the great bulk of the nitrogen is present in the soil is unsuitable for them. Notwithstanding, therefore, the small amount of nitrogen contained in cereal crops, they rank among those most benefited by nitrogenous manures. Phosphates, though of little use by themselves, are also beneficial (especially in the case of spring crops) when applied with nitrogenous

manure. A nitrogenous guano, or an application of nitrate of sodium and superphosphate, is generally the most effective manuring for a cereal crop.

Meadow Hay.—The grasses which form the main bulk of hay belong to the same family of plants as the cereal crops; the seed, however, in grass bears such a small proportion to the stem and leaf that meadow hay may be regarded as a straw crop. In accordance with this character hay is found to contain a much larger proportion of potash and lime than cereal crops, and a much smaller amount of phosphoric acid.

The roots of grass being far shorter than those of the cereals are less able to collect ash constituents from the soil; if therefore grass is mown for hay, manures containing potash, lime, and phosphoric acid will generally be required. Like the cereal crops grass is greatly increased in luxuriance by the application of soluble nitrogenous manures.

Farmyard manure, or the feeding of cake, corn, or roots on the land, is the most appropriate manuring for permanent pasture, if quality as well as quantity of produce is considered. Large crops of hay may be obtained by manuring with nitrate of sodium, together with kainit and superphosphate, but a continuance of such treatment promotes a coarse herbage.

The natural clovers of a meadow are destroyed by the continued application of highly nitrogenous manures, a hay consisting almost exclusively of grass being produced. The clovers are developed by the application of manures supplying potash and lime, and by pasturing instead of mowing.

The perennial character of grass, and the abundance of humus in a pasture soil, present favourable conditions for the collection of nitrogen from the atmosphere; this takes place to a greater extent on pasture land than with most other crops.

Leguminous Crops.—Some of these are grain crops, as beans and peas; others are fodder crops, as red clover, sainfoin and lucerne. A striking characteristic of all these crops is the large amount of nitrogen which they contain, the quantity being about twice as great as that found in cereal crops. The quantity of potash and lime in leguminous crops is also very large. The relative proportion of these two bases varies much in crops grown on different soils; upon a calcareous soil lime will preponderate in the crop, but on a clay soil potash. The lime is found chiefly in the leaf. Silica is nearly absent in leguminous crops.

The nutrition of leguminous crops is not at present perfectly understood. A good crop of red clover, when cut for hay, removes a large quantity of nitrogen from the land, but it nevertheless leaves the surface soil actually richer in nitrogen than it was before from the residue of roots and stubble left in the soil. From whence is this large quantity of nitrogen obtained? It must be procured either from the subsoil, or the atmosphere. The former seems the more probable, as experiments have hitherto failed to prove that leguminous plants have any special power of obtaining nitrogen from the air. The question is further complicated by the fact that nitrogenous manures generally produce but little effect upon leguminous crops. It seems pretty certain that leguminous crops possess to some extent a distinct source of nitrogen; they are pro-

bably capable of feeding on some compounds of nitrogen and carbon which are comparatively useless to other crops, and hence the facility with which they acquire nitrogen from the soil. A deeply rooted crop like red clover collects nitrogenous compounds from the subsoil, and accumulates nitrogen at the surface in the form of a crop.

The particular food supply of a leguminous crop becomes exhausted by repeated cropping, and the land is said to be "clover" or "bean sick;" no means of remedying this condition is known save by the growth of other crops for a series of years.

Potash manures have generally a very beneficial effect upon leguminous crops; they fail, however, to cure clover sickness. Gypsum is also valuable, though to a less extent.

Root Crops.—All these crops contain a large amount both of nitrogen and ash constituents; among the latter potash greatly preponderates. Turnips contain more sulphur than any other farm crop.

The turnip and mangel crop differ in several respects. Turnips and swedes draw their food chiefly from the surface soil. Their power of taking up nitrogen from the soil is distinctly greater than that of the cereal crops. Turnips are also well able to supply themselves with potash when growing in a fertile soil, but they have singularly little power of appropriating the combined phosphoric acid of the soil; fresh applications of phosphatic manures thus always produce a marked effect on this crop.

Mangels have far deeper roots than turnips, and also a longer period of growth. They have a great capacity for drawing food from the soil, including both nitrogen,

potash, and phosphoric acid. When carted off the land they are probably the most exhaustive crop that a farmer can grow. As mangels have not the same difficulty that turnips have of attacking the combined phosphoric acid of the soil, phosphatic manures are, in their case, of much less importance. Purely nitrogenous manures, as nitrate of sodium, when applied alone to mangels, generally produce a great effect on the crop; this is not the case with turnips, which require phosphates as well as nitrogen in their manure.

As both turnips and mangels consume extremely large amounts of plant food, a liberal general manuring with farmyard manure is in most cases essential for the production of a full crop; but the special characteristic of the manure for turnips should be phosphatic, and of that for mangels nitrogenous.

Potatos are surface feeders, and require a liberal general manuring to ensure an abundant crop.

As both root crops and potatos require large supplies of potash, kainit will be found of service on land naturally poor in that ingredient. It will be chiefly required when the crops are raised with artificial manures only, as farmyard manure will always supply a considerable amount of potash.

Forest Growth.—The figures given in the table represent the composition of the produce of beech, spruce fir, and Scotch pine forests felled for timber, and are the results of extensive investigations made in Bavaria. Nitrogen, sulphur, and chlorine determinations are wanting.

The amount of dry matter in the annual forest growth

is in excess of that yielded by any of the cultivated crops given in the table, excepting mangels. This large produce is obtained by a very small consumption of soil food; the amounts of potash and phosphoric acid required are especially far less than in the case of any farm crop. The greater part both of the ash constituents and nitrogen is found in the fallen leaves; if these are left undisturbed, and allowed to manure the ground, the requirements of the forest become extremely small. It appears that about 3000 lbs. of perfectly dry pine timber are produced with a consumption of only 2½ lbs. of potash, and 1 lb. of phosphoric acid per acre per annum; with beech timber the quantities required are rather larger. The nitrogen contained in timber is very small in amount, but the actual quantity required by a forest has not been accurately ascertained. The growth of forest timber is plainly far less exhaustive to the soil than ordinary farm culture. The demand on the soil becomes, however, considerably greater if the trees are cut when young, young timber and small branches being far richer both in nitrogen and ash constituents than the mature wood.

Adaptation of Manures to Crops.—The true economy of manure can be understood only when we are acquainted with the special characters of the crops we cultivate. The composition of a crop is no sufficient guide to the character of the manure appropriate to it, even when we possess in addition the composition of the soil on which it is to be grown. It is not only the materials required to form a crop, but the power of the crop to assimilate these materials which must form the basis of our judgment. This fact has been much overlooked by many scientific

writers, who have counselled farmers to manure their land in every case with all the constituents required by the crop, a proceeding both impracticable and unnecessary. In the case of a barren sand it may indeed be requisite to supply all the constituents of plant food before a crop can be grown, but such a case is far from the circumstances of ordinary agriculture.

When land is in a fertile condition the total amount of plant food available for crops is very considerable, and luxuriant growth may be obtained by supplementing the stores of the soil with the few particular elements of food which the crop it is wished to grow has most difficulty in obtaining. Thus, in a large majority of cases, a dressing of nitrate of sodium and superphosphate will ensure a full crop of wheat, barley, or oats, and in many cases nitrate of sodium alone will prove very effective. These cereal crops generally find the supply of nitrates in the soil insufficient for their full growth, and the supply of phosphates more or less inadequate; but in a majority of cases they are well able to obtain a sufficient supply of potash, and other essential elements of food. We are thus able, by supplying one or two constituents of the crop, to obtain a luxuriant harvest. In the same way nitrate of sodium employed alone will, in most cases, produce a large crop of mangels; superphosphate alone, a large crop of turnips; while potassium salts alone may be strikingly effective with pasture and clovers.

This special manuring for each crop is no strain on the capabilities of the soil if a rotation of crops be followed. If superphosphate is applied for the turnips, potash for the seeds, and a nitrogenous manure for the cereal crops, the more important elements of plant food contained in

the soil will not be diminished at the end of the rotation. At the same time the most economic result will have been obtained from the manures employed, for each manure will have been supplied to that particular crop with which it yields the most remunerative result.

It is doubtless possible by means of rotations manured on the above principles to farm successfully with the sale of all the crops produced, and without the use of farmyard manure; this is possible at least so long as artificial manures can be obtained at a low price. In the majority of cases, however, the special manuring will only be required to supplement the general manuring by farmyard manure. Under these circumstances it would seem best, from a chemical point of view, to apply the farmyard manure to those crops which most require potash, or which stand most in need of a general manuring; such crops would be pasture, seeds, turnips and potatos.

The economic value of potash manures varies much on different soils. As potassium salts are an expensive manure, the farmer should always ascertain by means of small field experiments whether they will, in his case, yield a remunerative result, before employing them on any large scale.

As the whole object of artificial manuring is to supplement the deficiencies of the soil, it is highly desirable that a farmer should ascertain by trials in the field what is the actual amount of increase which he obtains from the application of the manures he purchases. A few carefully made experiments will teach him what his land and crops are really in need of. Should he add superphosphate with the nitrate of sodium for his wheat? What dressing of the nitrate is most economical? Is superphosphate alone

sufficient for his turnip crop, or should guano or nitrate be employed as well? What is the smallest quantity of superphosphate sufficient for the crop? Will it pay to use potassium salts for his seeds or pasture? These and many other questions can only be answered by trials on his own fields, and on the farmer's knowledge of such facts will depend the economy with which he is able to use purchased manures.

Influence of Climate and Season.—The influence of weather upon crops is far greater than the influence of manure.

As a plant contains water as its largest constituent, and as the whole of the plant food obtained from the soil is taken up through the medium of water, while the amount of water daily lost by the plant through evaporation is very large, the necessity of a sufficient supply of water in the soil during the growing period of a crop is very evident. On the other hand, an excess of water in the soil prevents root development, and causes a loss of nitrates and other soluble plant foods in the drainage water. Deeply rooted crops, as wheat, red clover, and mangel, are those best fitted to resist drought; while shallow-rooted crops, as grass and turnips, are those which suffer most from it.

We have already seen that carbon, which forms the largest ingredient of all vegetable substances, is obtained by plants exclusively from the atmosphere under the influence of light, and that a certain temperature is necessary for this assimilation of carbon, and for the other chemical processes which proceed in a growing plant; a sufficient supply of light and heat is therefore plainly required for the production of a crop. In a season of de-

ficient light and heat the harvest is always late, growth having taken place more slowly than in an average season. In the case of extremely cold and cloudy summers the whole season may be too short for maturing the crop, and the seed in consequence may never be fully ripened.

Each crop requires more or less a different climate for its perfect development; a knowledge of the kind of climate best suited to each crop is of great service in selecting crops for any particular district. Thus wheat requires hot and dry weather for its ripening period, while oats will ripen in a moist atmosphere. Mangels require heat, and can resist drought, while turnips develope best in a cool moist air. Oats and turnips thus best suit a Scotch climate, while wheat and mangels are better fitted for the south-east of England.

The soil best furnished with plant food is the one which will yield the best results in adverse seasons, the crop having a greater amount of vitality, and being able to turn to the best advantage the short periods of favourable weather that may occur. Poor soils yield their best results in seasons of slow but continued growth, the crop having a longer time to collect the scanty supply of food which the soil contains. In hot seasons, with an early harvest, only soils well supplied with food can produce full crops.

The character of the winter has often considerable influence on that of the following season. In a wet winter the soil may lose nitrates by drainage to a considerable extent. Root development will also be prevented by excessive wet. After such a winter the wheat crop generally is in a backward condition, and finds itself in an impoverished soil. The injurious effects of severe frost are well known.

CHAPTER V.

ROTATION OF CROPS.

The aim of rotations—Results of bare fallow—Effect of green crops, fed on the land or ploughed in—Distinctive characteristics of crops—Differences in periods of growth, depth of roots, powers of assimilation, and quantity of food demanded—Losses to the land during rotation—Actual loss in an assumed four-course rotation—Probable gain of nitrogen from the atmosphere—Sale of produce other than corn and meat.

It is by no means impossible to grow the same crop with success year after year on the same land; ordinary pasture is indeed an example of continuous cropping. The Rothamsted experiments show that excellent crops of wheat, barley, and mangel may be continuously obtained if appropriate manure is annually applied, and the land kept free from weeds. A rotation of crops is resorted to in ordinary practice from the facilities which such a plan affords for cleaning the land, and from the greater economy of manure which results from this practice. One of the principal aims of a rotation is to bring the land from time to time into a condition suitable for growing cereal crops; this suitable condition consists mainly in the accumulation of nitrogenous plant food in the surface soil.

Bare Fallow.—A bare fallow is one of the oldest modes of preparing soil for wheat. The soil is ploughed, and exposed a whole year to atmospheric influences, and

finally sown with wheat. In the case of a clay soil, this treatment would probably lead to the following results:— 1. An improvement in the mechanical texture of the soil. 2. The disintegration of some of the mineral silicates, whereby potash and other necessary ash constituents of plants would be liberated and made available for vegetation. 3. The absorption of ammonia from the atmosphere by the soil. 4. The receipt of both ammonia and nitric acid from the air in the form of rain. 5. The oxidation of ammonia, and of the vegetable remains in the soil, nitric acid being produced.

The production of nitric acid is probably the most important result of a bare fallow. In soils at Rothamsted left as bare fallow, there has been found at the end of summer 34—55 lb. of nitrogen per acre in the form of nitric acid in the first 20 inches from the surface. Supposing the season of fallow is a fairly dry one, the increase in the available nitrogenous food will probably enable the soil to produce twice as much wheat as it could do without this treatment. If, however, the soil is exposed to heavy rain, the nitrates produced will be more or less washed out, and the benefit of the fallow greatly diminished. Bare fallow can be used systematically with advantage only on clay soils having a considerable absorptive power for ammonia, and in a tolerably dry climate; under other circumstances a continuance of the practice must issue in a serious loss of soil nitrogen.

Green Crops.—The most usual plan for bringing land into condition for the growth of cereals is the cultivation of green crops. These may be ploughed in, forming what is termed green manuring; or consumed on the land by

the farm stock; or the crop may be removed, consumed in cattle-sheds or in the farmyard, and the resulting manure brought on to the land. The principle in every case is that the constituents of the crop shall be returned to the soil.

Let us suppose that land is laid down with seeds, which after two or three years are ploughed up, and a cereal crop taken. While the land is continuously covered by vegetation the loss of nitric acid by drainage will be reduced to a minimum. If the grass is fed off on the land, the surface soil will at the end of the three years be considerably enriched both with ash constituents and nitrogen. The former have been collected from the subsoil by the roots of the crop, and returned to the surface as animal manure. The latter includes the accumulated receipts from the atmosphere during the three years, minus the quantity lost by drainage and that assimilated by the animals. The accumulated nitrogen will be chiefly in the form of grass roots, stems, and humus. When such land is ploughed up, the vegetable matter and humus are oxidised, and gradually yield their nitrogen as nitric acid.

Such a mode of cropping has an advantage over a bare fallow in several ways:—1. The land is turned to profitable use, food being produced for the farm stock. 2. Both ash constituents and nitrates are collected from the subsoil, and brought to the surface. 3. The nitrogen is kept in an insoluble form, as vegetable matter, and consequently cannot be washed away, but accumulates to a greater extent than in a bare fallow. 4. Humus is produced, the beneficial actions of which have already been noticed. We have laid no stress on the enrichment of the

land by means of ammonia taken up from the atmosphere by the leaves of the crop, for nothing is known as to the quantity of nitrogen which crops may thus acquire.

It follows from what we have just stated that the benefits resulting from the growth of a green crop in a rotation are greater in proportion as its period of growth is longer, and its roots deeper. The more these conditions are fulfilled the larger will be the accumulation at the surface both of nitrogen and ash constituents, and the greater consequently the increased fertility of the soil.

Leguminous crops, as already mentioned, have a special power of accumulating nitrogen in the surface soil, and are hence of the greatest value in a rotation. Red clover is the most striking instance of this action. Its roots extend further perhaps than those of any other farm crop, and being biennial it has a long period for growth. The accumulation of nitrogen at the surface in the form of roots, stubble, and decayed vegetable matter, is in the case of a good crop of clover so considerable, that the whole of the above ground growth may be removed as hay, and the land yet remain greatly enriched with nitrogen, and in an excellent condition for producing a crop of wheat.

The ploughing in of green crops has some advantages over the feeding of crops on the land. By this mode of proceeding the whole of the crop is returned to the soil, whereas in feeding a small part of the nitrogen and ash constituents is retained by the animal. The characteristic advantage of green manuring lies, however, in the large amount of humus which the soil acquires. All the carbon which the crop has obtained from the atmosphere is in this case incorporated with the soil, instead of being consumed by the animal. Green manuring is especially

adapted for light sandy soils, which need humus to increase their retentive power.

Having glanced at the general advantages to be derived from alternating green crops with cereals, we will consider next the characteristics of different crops which specially fit them to succeed or prepare for each other.

Distinctive Characteristics of Crops.—Differences in their periods of growth occasion a marked distinction in the relation of different crops to soil nitrogen. Thus the fact that the active growth of the cereals commences in spring, and concludes at their time of blooming towards the end of June, places these crops at a disadvantage as to the supply of nitrates from the soil. The autumn and winter rains have frequently washed out the greater part of the nitrates contained in the soil before the growth of the cereal crop commences, and nitrification in the soil has not long recommenced its activity in summer time when the crop becomes too mature to appropriate fresh supplies of nitrogen. Continuous wheat cropping thus results in a gradual impoverishment of soil nitrogen by winter drainage, over and above the nitrogen actually removed in the crops, and thus necessitates a considerable application of nitrogenous manure if fertility is to be maintained.

A root crop sown in early summer, on the other hand, has at its disposal all the nitrates that would be available for wheat or barley, and in addition the large supply of nitrates formed in the soil during summer and early autumn. A great part of the nitrates which would be lost in cereal cultivation is thus assimilated and retained by a root crop, and such crops are found to stand in less

need of nitrogenous manure than cereals. By consuming the roots on the land the nitrates collected by the crop are returned to the soil in the form of animal manure, and the land thus prepared to carry a cereal crop. Similar remarks might be made respecting other green crops whose active growth extends into the autumn.*

Another important difference between crops lies in their range of roots. Deeply rooted crops, as red clover, sainfoin, rape, and mangel, and among the cereals wheat, and rye, are to a considerable extent subsoil feeders, and have a greater power of obtaining ash constituents from the soil than shallow-rooted crops, as white clover, potatos, turnips, and barley. In accordance with this we find that superphosphate is a very effective manure for the last three crops, but is much less required by such crops as mangel or wheat. By growing deeply-rooted crops as part of a rotation the subsoil is made to contribute to the general fertility. Shallow-rooted crops, on the other hand, have generally a special faculty for appropriating food accumulated at the surface, and are often of great use in this respect, as when barley is made to follow turnips fed off on the land.

Very little is definitely known as to the capacity of different crops for assimilating different forms of plant food, but there can be no doubt that this also is one of the distinctions between various crops, and one reason of the economy of a rotation. The most plainly marked distinction as to mode of feeding is afforded by the behaviour of various crops towards silica. Graminaceous crops, as the cereals and grasses, are apparently capable

* The writer is indebted to Mr. Lawes for the important ideas contained in the two preceding paragraphs.

of assimilating certain of the silicates contained in the soil; other crops exhibit no such capacity. In such a case it is easy to imagine that an alternation of cereals with crops of a different description may be for the benefit of both, each drawing to some extent upon distinct supplies of food. Again, leguminous crops are clearly able to assimilate nitrogen to a far greater extent than cereals, and probably in some measure from a different source. If crops of winter beans and winter wheat are grown on similar unmanured land, the bean crop will generally contain twice as much nitrogen as the wheat. The land is not however impoverished for wheat by the growth of beans, for wheat after beans will be a far better crop than wheat after wheat, thus affording a striking example of the advantages of rotation.

The quantities of plant food required by different crops are given in the table printed on page 38; these also furnish reasons for the alternation of crops. It will be seen, for instance, that the cereals require but little potash and lime, while root crops, beans, and clover, demand a large supply; it is obvious, therefore, that the resources of the soil are husbanded by growing these two classes of crops in alternation, the greater demand for potash and lime thus falling every alternate year.

The nett result of a judicious alternation of crops, in which the special characteristics of each are turned to good account, is the production of a maximum total yield of produce with a minimum amount of manure.

Losses to the Land during Rotation.—The table showing the composition of ordinary farm crops will supply the requisite information as to the loss which a farm may

suffer by the sale of individual crops. We will now consider briefly the losses during a rotation.

The conservation of plant food on a farm is generally effected by confining the exports to corn and meat, the rest of the produce being consumed by the stock, and the manure returned to the land. Let us assume that a farm is managed on the four-course system, and that the average crops obtained per acre are—swedes, 14 ton; barley, 40 bush.; seeds (half clover, half grass), 3 ton of hay; and wheat, 30 bush. Further, that nothing is sold save corn and meat; that 2 bush. both of wheat and barley are returned to the land as seed; that 700 lb. of linseed cake are fed with each acre of swedes; that 110 lb. of oats are purchased per acre per annum for the horses. Finally, that half a ton of straw is fed per acre in the course of the rotation, and the rest used as litter. The soil will in this case suffer the following losses of nitrogen, phosphoric acid, and potash, in the course of a four years' rotation.

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LOSSES PER ACRE DURING A FOUR-COURSE ROTATION.

	Nitrogen.	Phosphoric acid.	Potash.
	lbs.	lbs.	lbs.
By feeding swedes, 14 ton . .	11·1	1·89	0·24
By sale of barley, 38 bush. .	32·3	14·35	9·60
By feeding seeds, 3 ton hay . .	18·7	3·20	0·40
By sale of wheat, 28 bush. .	30·8	13·35	9·05
By feeding straw, ½ ton. . .	0·7	0·12	0·02
	93·6	32·91	19·31
Deduct manure from 440 lb. oats, and 700 lb. oilcake . . .	36·8	14·61	12·02
Total loss in 4 years . . .	56·8	18·30	7·29
Average loss each year . .	14·2	4·57	1·82

These losses assume that the farmyard manure is properly made, and returned to the land without waste. If the manure has suffered loss by drainage the estimates given would have to be increased.

The loss of potash is extremely small, and may generally be quite disregarded. If, however, no cake is used, and the land is poor in potash, the loss might be replaced by the use of 1 cwt. of calcined kainit for the seeds.

The loss of phosphoric acid would be more than replaced, even if no cake were employed, by the use of 2 cwt. of superphosphate for the swedes.

The loss of nitrogen by the sale of crops and meat is seen to be far more considerable than the loss of phosphoric acid or potash. The figures given are also below the truth, as they do not take into account the nitrates lost to the soil by drainage. Against this loss of nitrogen we have to place the amount annually supplied to the land by the rainfall, say 6—8 lb. per acre, and also the unknown quantity absorbed as ammonia from the atmosphere by soil and plant; this latter amount will vary with the nature of the soil and climate, and probably also with the character of the cropping. We may, however, safely assume that with the cropping and manuring supposed in the preceding table the total gain of nitrogen from the atmosphere will balance the loss, so that under good management the rotation might be indefinitely continued without diminishing the fertility of the land.

In the four-course manured rotation upon the heavy land at Rothamsted, the nitrogen annually removed in the crops, on an average of thirty-two years, has exceeded by about 35 lb. the quantity supplied in the manure. If the crops on this experimental rotation should be permanently

maintained in quantity, of which at present we cannot be certain, we must conclude that this 35 lb. of nitrogen, together with the unknown additional quantity lost as nitrate by drainage, have been annually derived from the atmosphere—partly as rain, but mostly by direct absorption by soil or crop. It appears very probable that on many soils the amount of nitrogen contributed by the atmosphere in the course of a rotation is very considerable.

We have supposed that only corn and meat are sold off the land during the rotation; it will often be economical to sell a larger part of the produce, and to purchase manure in its place. The sale of straw will be attended with little practical loss on heavy land; but on light land both the loss of potash, and the diminution in the bulk of the manure will be more or less felt. The sale of hay or roots is far more exhaustive, and except on the most fertile soils, must demand a considerable purchase of manure or cattle food to replenish the soil with plant nourishment.

CHAPTER VI.

ANIMAL NUTRITION.

The Constituents of the Animal Body.—Water, albuminoids, gelatinoids, horny matter, fat, and ash constituents—Composition of animals in various stages of growth and fattening—Proportion of carcase—Composition of increase whilst fattening. *The Processes of Nutrition.*—The constituents of food, and their particular functions in the body—Digestion—Respiration—Excretion.

In order to understand the mode in which animals are nourished we must first obtain some acquaintance with the nature of the animal body, and understand the composition of the increase which takes place during growth and fattening.

The Constituents of Animals.—The elements composing the animal frame are the ten already named as forming the essential constituents of plants (page 2), with sodium and chlorine in addition. The two last named elements are commonly present in the succulent parts of plants, but are apparently not essential to plant life—in the animal frame they are, however, indispensable. Fluorine and silicon are also always found in the animal body, but are not known to be essential for life or growth; fluorine occurs in small quantities in the teeth and bones, and silicon in hair, wool, and feathers.

The combustible matter of the animal body is mainly composed of nitrogenous substances, and of fat.

The nitrogenous substances constituting the animal frame may be generally classed as—(1) albuminoids; (2) gelatinoids; and (3) horny matter. These three groups are related in composition, though differing a good deal in their properties. The albuminoids form the substance of animal muscle and nerve, and the greater part of the solid matter of blood; they are, undoubtedly, of the first importance in the animal economy. The gelatinoids form the substance of skin and sinew, of all connective tissue, and also the combustible matter of cartilage and bone. Horny matter, named by chemists keratin, is the material of which horn, hair, wool, and feathers are constituted.

The fats occurring in the animal body are principally stearin, palmitin, and olein. Stearin preponderates in hard fats, and olein in fluid fats.

Of the incombustible constituents by far the largest part is contained in the bones. In fat animals 75 to 85 per cent. of the total ash constituents are found in the bones. Bone ash chiefly consists of phosphate of calcium, with a small quantity of carbonate of calcium and phosphate of magnesium. In muscle by far the most abundant ash constituent is phosphate of potassium. Potassium salts are also abundant in the "yolk" of unwashed wool. Blood, on the other hand, always contains a considerable quantity of sodium salts.

The amounts of water, nitrogenous matter, fat, and ash constituents present in a large number of animals have been determined at Rothamsted. The following table shows the percentage composition of eight animals,

after deducting the contents of the stomachs and intestines:—

PERCENTAGE COMPOSITION OF WHOLE BODIES OF ANIMALS.

	Fat calf.	Half fat ox.	Fat ox.	Store sheep.	Fat sheep.	Extra fat sheep.	Store pig.	Fat pig.
Water . . .	65·1	56·0	48·4	61·0	46·1	37·1	58·1	43·0
Nitrogenous matter.	15·7	18·1	15·4	15·8	13·0	11·5	14·5	11·4
Fat	15·3	20·8	32·0	19·9	37·9	48·3	24·6	43·9
Ash . . .	3·9	5·1	4·2	3·3	3·0	3·1	2·8	1·7

The fat pig was one grown for fresh pork, not for bacon.

Water is in nearly every case the largest ingredient of the animal body; the proportion of water diminishes with the growth of the animal, and especially during fattening. Fat forms in most cases the principal solid ingredient of well fed animals, its proportion increases very largely during fattening. The proportion of nitrogenous matter and ash tends to increase from youth to maturity, but diminishes during fattening.

The largest proportion of nitrogenous matter and of ash are found in the ox, the smallest in the pig. The difference in the proportion of ash is chiefly due to the wide difference in the proportion of bone in these two animals. Fat is found in greatest quantity in the pig, and is least in the ox.

The following table shows the quantity of nitrogen, and of the principal ash constituents, in the fasted live weight of the fat animals analysed at Rothamsted. For convenience of comparison each animal is assumed to weigh 1000 lb. The table also gives the nitrogen and ash constituents in wool and milk; it thus supplies full informa-

tion as to the loss which a farm will sustain by the sale of animal produce. The composition of wool is mainly deduced from foreign analyses.

ASH CONSTITUENTS AND NITROGEN IN 1000 POUNDS OF VARIOUS ANIMALS AND THEIR PRODUCTS.

	Nitrogen.	Phosphoric acid.	Potash.	Lime.	Magnesia.
Fat ox . .	23·18	16·52	1·84	19·20	0·63
Fat sheep . .	19·60	11·29	1·59	12·80	0·50
Fat pig . .	17·57	6·92	1·48	6·67	0·35
Wool, unwashed	73·00	1·00	40·00	1·00	0·70
Milk . . .	6·40	2·00	1·70	1·60	0·20

These figures show that the ox contains in proportion to its weight a larger amount of nitrogen, and a much larger amount of phosphoric acid and lime, than either the sheep or pig. Of all the animals raised on a farm the pig contains least of all the important ash constituents.

The large amount of potash in unwashed wool is very remarkable; a fleece must sometimes contain more potash than the whole body of the shorn sheep.

In a fat ox about 60 per cent. of the fasted live weight will be butchers' carcase; in a fat sheep about 58 per cent.; in a fat pig (fatted for pork) 83 per cent. The proportion of carcase increases considerably during fattening. Thus the carcase in the store sheep killed at Rothamsted averaged 53·4, in the fat sheep 58·6, and in the very fat sheep 64·1 per cent. of the fasted live weight.

When a lean animal is fattened the larger part of the increase in live weight is carcase. It was found at Rothamsted that in the case of sheep passing from the "store" to the "fat" condition, increasing in weight

from 102 lb. to 155 lb., about 68 per cent. of the increase was carcase. With "fat" sheep passing to the "very fat" state, increasing from 144 lb. to 202 lb. live weight, the proportion of carcase in the increase was about 77 per cent. With a fattening pig, increasing from 103 lb. to 191 lb. live weight, the proportion of carcase in the increase was found to be 91 per cent.

The percentage composition of the increase of sheep and pigs when passing from the "store" to the "fat" condition is about as follows. The increase of fattening oxen will have a similar composition.

PERCENTAGE COMPOSITION OF THE INCREASE WHILST FATTENING.

	Water.	Nitrogenous matter.	Fat.	Ash.
Sheep	22·0	7·2	68·8	2·0
Pigs	28·6	7·8	63·1	0·5

The increase during the fattening stage of growth is thus chiefly an increase in fat, eight to nine parts of fat being laid on for one of nitrogenous matter. The proportion of fat would be somewhat greater still in the increase of highly fattened animals, as, for instance, of pigs fed for bacon.

The Processes of Nutrition.—We have already seen that the food of plants is of the simplest character. From such simple substances as carbonic acid, nitric acid, water, and salts, a plant is able to construct a great variety of elaborate compounds. It accomplishes these surprising transformations by a consumption of force (sunlight)

external to itself. An animal has no such constructive power. The animal frame is built up of substances existing ready formed in the food, or produced by the splitting up or partial combustion of some of the food constituents in the body. The animal also derives little or no aid from external force. The temperature of the animal (about 100° Fahr.) is maintained by the heat generated within the body from the combustion of the food consumed; the force by which all the mechanical work of the animal is performed is also derived from the same combustion of food. The source of force in the animal is thus purely internal.

It is evident from what has just been said that the food of animals has duties to perform which are not demanded of the food of plants. In plants the food merely provides the matter for building up the vegetable tissues. In the animal, besides constructing tissue, the food has to furnish the means of producing heat and mechanical force.

1. **Food Constituents and their Functions.**—The solid ingredients of animal food may be classed generally as—(1) albuminoids; (2) fat; (3) carbo-hydrates; (4) incombustible matter, or ash. Besides these general ingredients of food we have in immature vegetable products a fifth class—the amides, which also take part in animal nutrition. The albuminoids and amides are nitrogenous substances, the other ingredients of food are non-nitrogenous.

The various albuminoids occurring in corn, roots, and other forms of vegetable food, are quite similar in composition to those found in milk, blood, and flesh. From the albuminoids of the food are formed not only the al-

buminoids of the animal frame, but also the gelatinoids, the hair, wool, horn, &c., and to some extent the fat. By the combustion of albuminoids in the body heat and mechanical force will also be developed. Albuminoids thus supply in themselves most of the requirements of the animal—a statement which can be made of no other food constituent. The albuminoids of food are frequently described in analyses as "flesh-formers."

An animal, even when not increasing in weight, will always require a certain constant supply of albuminoid in its food to replace the waste of nitrogenous tissue which is always going on; the amount thus required is but small, in the case of an adult man at rest it amounts to about fifty grams ($1\frac{3}{4}$ oz.) per day.

When the nitrogenous tissues, or the albuminoids consumed as food, are oxidised in the body, the nitrogen they contain is not burnt, but excreted in the form of urea. The urea produced is one-third the weight of the albumin oxidised. When the albuminoids, either of the food or of the wasting tissues, are only partially oxidised, fat as well as urea may be produced. Theoretically, 100 parts of albumin may yield 51·4 parts of fat.

When amides are consumed as food they are burnt in the system, and their nitrogen excreted as urea. Amides cannot supply the place of albuminoids as muscle-formers, but by combustion they serve for the production of heat and force.

The fatty matter contained in food is similar to that found in the animal body, but an animal is apparently capable of transforming one kind of fat into another. The fat of the food is either burnt in the animal system to furnish heat and mechanical energy, or it is stored up as

a reserve of force. Fat has a greater value as a heat and force producer than any other ingredient of food.

The carbo-hydrates of the food include starch, sugar, and cellulose; these substances consist of carbon, hydrogen, and oxygen, the last two elements being in the proportion to form water—hence the name. Various other non-nitrogenous constituents of food, as pectin, lignose, and vegetable acids, are also generally included under this title, though not strictly speaking carbo-hydrates. Carbo-hydrates form the largest part of all vegetable foods. They are not permanently stored up in the animal body, but serve, when burnt in the system, for the production of heat and mechanical work. They are also capable, when consumed in excess of immediate requirements, of conversion into fat.

Carbo-hydrates are of less value, for the same weight consumed, than either albuminoids or fat. Frankland found that 100 parts of fat when burnt gave the same amount of heat and force as 211 parts of albumin (urea deducted), or 232 parts of starch. It is commonly reckoned that 1 part of fat is equivalent to 2·44 parts of starch. Cane sugar, according to the Rothamsted experiments with pigs, has the same feeding value as starch. Cellulose, being more difficult of digestion, has probably a smaller value than either.

The amides, carbo-hydrates, and fat, are quite incapable of adding to the nitrogenous tissues of the body. They may, however, have this effect indirectly by protecting the albuminoids of the food from oxidation. A moderate quantity of albuminoids supplied to a growing animal will thus produce a larger increase of muscle when accompanied by a supply of carbo-hydrates or fat than if con-

sumed alone. In the former case the non-nitrogenous ingredients of the food supply the heat and force demanded by the animal body, in the latter case the albuminoids have to meet every requirement.

If an adult animal receives the small quantity of albuminoids and ash constituents necessary to supply the waste of tissue, the whole of its remaining wants may probably be met by supplies of carbo-hydrates and of fat.

The ash constituents present in the food are the same as those found in the animal body; all that is accomplished by the animal is to select from the supply those of which it is in want.

2. **Digestion.**—The object of digestion is to bring the solid constituents of the food into a form suitable for absorption into the blood. Of the carbo-hydrates of the food some, as sugar, are already soluble and diffusible, and need no digestion; others, as starch and cellulose, are naturally insoluble. The digestion of carbo-hydrates commences with the action of the saliva, which has the property of converting starch into sugar. This action, in the case of ruminants, is prolonged by the temporary sojourn of the food in the first two stomachs, and its return to the mouth in chewing the cud. The further solution of starch and cellulose is effected in the intestines, partly by the pancreatic juice, which has a powerful action on starch, and partly by the fermentive processes which take place.

The albuminoids of the food are attacked by the gastric juice of the stomach (the fourth stomach of ruminants), and converted into peptones, bodies similar to albuminoids in composition, but which, unlike them, are diffusible

through a membrane. The pancreatic juice of the small intestines also converts albuminoids into peptones.

Fat, liquefied by the heat of the body, is probably capable of absorption without change. The digestion of fat in large quantities is greatly assisted by the bile and pancreatic juice.

The absorption of the dissolved constituents of the food takes place more or less in all parts of the alimentary canal, but chiefly in the small intestines. The absorbed matters pass into the blood.

The blood of an animal is the source of nourishment to the whole body; out of its ingredients all the tissues are formed. The blood is also the means of conveying the oxygen to the tissues which is essential to their vitality, and of removing from them carbonic acid, and the other products of their metamorphosis.

3. **Respiration.**—The blood is supplied with oxygen during its passage through the lungs, where it is brought into contact with air. The oxygen is absorbed by the hœmoglobin, which forms the chief constituent of the red blood corpuscles. The scarlet blood thus produced is circulated through the whole body by the arteries; the oxygen it supplies is consumed in the tissues, producing, among other results, heat and mechanical work. The blood finally returns from the tissues by the veins. The hœmoglobin has then lost its oxygen, and has assumed a purple colour; the blood serum also contains carbonic acid gas in solution, and many other products of decomposition. By passing again through the lungs the carbonic acid is more or less completely discharged, and a fresh supply of oxygen obtained.

4. Excretion.—The products which result from the oxidation of tissue, or of the food consumed, are removed from the body by the lungs, the kidneys, or the skin. The chief products of oxidation in the body are carbonic acid, water, urea, and salts. Carbonic acid is removed through the lungs, and to a smaller extent by the skin; urea and salts by the kidneys; water by all the organs of excretion.

Non-nitrogenous substances, as fat and sugar, when oxidised in the body, yield simply water and carbonic acid. The nitrogen of the albuminoids, gelatinoids, and amides is not oxidised, but is excreted in the form of urea. The sulphur of the albuminoids is apparently oxidised to sulphuric acid.

The quantity of nitrogen in the urine is a measure of the albuminoids, gelatinoids, and amides oxidised in the body. In the urine are also removed all the salts not required for the animal economy; sodium and potassium salts are generally abundantly present.

The solid excrement contains the undigested parts of the food, with the residues of the bile, and other secretions of the alimentary canal.

CHAPTER VII.

FOODS.

The Composition of Foods.—Detailed composition—Proportion of nitrogen existing as true albuminoids—Variation in foods due to age and manuring—Proportion between nitrogenous and non-nitrogenous constituents—Ash constituents. *Digestibility of Foods.*—Method of determination—Experiments with ruminants—Influence of age of animal, daily ration, and labour—Influence of the maturity of fodder crops on their digestibility—Influence of one food on the digestibility of another—Common salt—Experiments with horses—Experiments with pigs—Experiments with geese. *Comparative Nutritive Value of Foods.*—Influence of proportion of water—Comparative heat and work producing power—Proportion of albuminoids to non-albuminoids—General conclusions.

In the preceding chapter we have enumerated the chief constituents of food, and described their functions in the animal body; we may now proceed a step further, and consider the detailed composition and feeding value of the foods actually employed on the farm.

The nourishing value of a food is plainly fixed by two factors:—1. Its composition. 2. Its digestibility. The first of these determines the character of the food—its richness in albuminoids, fat, carbo-hydrates, and ash constituents. The second determines the extent to which these various constituents are made use of in the animal body.

Composition of Foods.—The average percentage composition of the foods commonly given to farm animals is

shown in the following table. The figures given are in every case the mean of a large number of analyses.

PERCENTAGE COMPOSITION OF ORDINARY FOODS.

Food.	Water.	Albuminoids.	Fat.	Soluble carbo-hydrates.	Fibre.	Ash.
Cotton cake (decorticated)	10·0	41·2	14·0	18·0	9·0	7·8
Cotton cake (undecorticated)	11·5	24·6	6·2	30·2	20·8	6·7
Linseed cake	12·0	28·1	12·0	30·3	11·0	6·6
Beans	14·5	25·5	1·6	45·9	9·4	3·1
Peas	14·3	22·4	2·0	52·5	6·4	2·4
Oats	13·0	12·9	6·0	53·8	10·8	3·5
Wheat	14·4	11·3	1·5	68·1	3·0	1·7
Barley	14·0	10·6	2·0	63·7	7·1	2·6
Maize	11·4	10·4	5·1	68·5	3·0	1·6
Malt dust	9·5	23·7	2·2	44·9	12·5	6·8
Wheat bran	14·0	14·2	4·2	50·4	11·1	6·1
Brewer's grains	77·4	4·8	1·4	9·7	5·3	1·5
Clover hay	16·0	12·3	2·2	38·2	26·0	5·3
Meadow hay	14·3	9·7	2·5	41·0	26·3	6·2
Bean straw	16·0	6·3	1·0	36·7	35·0	5·0
Wheat straw	14·3	3·0	1·5	32·6	44·0	4·6
Meadow grass	80·0	3·5	0·8	19·2	4·5	2·0
Green clover	83·0	3·3	0·7	7·0	4·5	1·5
Potatos	75·0	2·1	0·3	20·5	1·1	1·0
Mangels	88·5	1·2	0·1	8·2	1·0	1·0
Swedes	89·3	1·5	0·2	7·3	1·1	0·6
Turnips	91·7	1·1	0·2	5·3	1·0	0·7

The soluble carbo-hydrates in the above table include starc h, pectin, and the finer parts of the fibre; these are not soluble in water, but are dissolved by the weak acid and alkali employed by the analyst to separate the coarse fibre.

The whole of the nitrogen present in the foods above mentioned has been reckoned as existing as albuminoids. We are obliged to adopt this usual mode of calculation for the sake of uniformity, the amount of true albuminoids having been determined only in the case of a few of the foods enumerated.

It has been shown during the last few years that a part of the nitrogen in many foods exists, not as albuminoids, but as amides (*e.g.*, asparagine and glutamine) and as nitrates. The subject is at present receiving the attention of chemists. It appears that in seeds nearly the whole of the nitrogen exists as albuminoids, and this is especially true of the kernel of the seed. Thus in wheat flour about 90 per cent. of the nitrogen present is in the form of albuminoids, while in the bran which forms the skin of the grain only about 70 per cent. of the nitrogen is in this condition. For the various cakes and grains mentioned in the table the figures given for albuminoids will be approximately correct, but for the other foods the figures are undoubtedly too high. In hay it would appear, from the few determinations made, that about 80 per cent. of the nitrogen is present as albuminoids. In malt-dust about 73 per cent. of the nitrogen is albuminoid. In potatos about 60 per cent. of the nitrogen is in this condition. The few determinations made in swedes show about 45 per cent. of the nitrogen as albuminoids. While in mangels generally only about 25 per cent. of the nitrogen is in this form.

The composition of all vegetable foods is liable to variation, depending on the state of maturity of the plant, and the character of the soil and season. In the case of perfectly matured produce, as, for instance, ripe

seed, the variations in composition are not generally considerable, and an average composition, such as is given in the table, will be found in most cases pretty correct. But in the case of immature produce, such as meadow grass, turnips, or mangels, the composition largely depends on the stage of growth in which the plant is taken, and is also greatly affected by the character of the manuring. It may be generally stated that as a plant matures the proportion of water, nitrogenous matter, and ash constituents diminishes, while the proportion of carbo-hydrates largely increases. At the same time the amides become more or less converted into albuminoids.

The following table shows the percentage composition of meadow grass cut at three different dates in the same field. The first cutting will represent pasture grass fed off in the green state by stock; the second cutting is good ordinary hay; the third cutting is an over-ripe hay, somewhat coarse and stemmy, but well harvested. The composition given in every case is that of the dry substance :—

COMPOSITION OF HAY HARVESTED AT DIFFERENT DATES.

Date of cutting.	Albuminoids.	Fat.	Soluble carbo-hydrates.	Fibre.	Ash.
May 14 . .	17·65	3·19	40·86	22·97	15·33
June 9. . .	11·16	2·74	43·27	34·88	7·95
June 26 . .	8·46	2·71	43·34	38·15	7·34

Young grass is thus much richer in albuminoids,* and

* It must be borne in mind that in the present transition state of our analyses of food, the term "albuminoids" will generally include *all* the nitrogenous substances present.

contains a smaller proportion of indigestible fibre than older grass, and is consequently more nourishing. The same comparison may be made between young clover and that which is allowed to mature for hay. Hay should always be cut immediately full bloom is reached; after this point the quality of the crop will considerably deteriorate.

While fodder crops deteriorate towards maturity, from the conversion of soluble carbo-hydrates into fibre, crops such as potatos and mangel improve, the carbo-hydrates produced in their case being respectively starch and sugar, both of them substances of great feeding value.

The influence of high manuring is naturally to increase the luxuriance of a crop; a luxuriant crop will always contain more water than one in less active growth. Very large mangels often contain only 6 per cent. of dry matter, while in quite small roots the proportion may be as high as 15 per cent. Luxuriance also retards maturity. A heavily manured mangel will contain, at the same date, a much smaller proportion of sugar than a similar mangel grown on poor soil. The result of high manuring is thus not only to increase the bulk of the crop, but also generally to diminish the proportion of carbo-hydrates, and increase the nitrogen, ash constituents, and water. In highly manured crops a smaller proportion of the nitrogen will exist as albuminoids than in crops less heavily manured and more mature.

In the case of hay the composition is further affected by the conditions of harvesting. Grass that has suffered from rain during haymaking will contain less soluble matter (carbo-hydrates and albuminoids) than well made hay; this loss will be greatly increased if the hay has been

long in the field, and undergone fermentation as well as washing.

Having pointed out the variations which are liable to occur, we may now consider the average composition of the various foods shown in the table.

The amount of total dry matter is seen to be tolerably uniform throughout the various classes of dry foods, the foods richest in fat being generally the driest. In the green fodder and roots the proportion of water is generally very large; potatos contain the most, and white turnips the least proportion of dry matter.

We have already seen that albuminoids and fat are the most concentrated forms of food which an animal can consume; those foods which are rich in albuminoids and fat are therefore those which, generally speaking, have the highest nourishing value. At the head of all foods in this respect stand the various descriptions of oilcake; they are, without doubt, among the most concentrated foods at the farmer's disposal. The leguminous seeds, as beans, peas, and lentils, are rich in albuminoids, but not in fat. The cereal grains are much poorer in albuminoids, containing only about one-half the proportion found in leguminous seeds. Of the common cereals, oats are generally the most nitrogenous, and maize the least. Oats and maize are characterised by containing more fat than the other cereal grains. The special characteristic of all the cereal grains is their richness in an easily digested carbo-hydrate, starch.

Of the three cereal products mentioned in the table the bran and brewer's grains represent respectively the husk of wheat and barley. These foods are richer both in nitrogenous matter and fat, but contain a much more

considerable proportion of fibre than the whole grain. Malt-dust (known also as malt-combs) consists of the radicles of the germinated barley, which are removed after the malt has been dried. This material is very rich in nitrogenous matter.

When we turn to the hay, straw, green fodder, and roots, the general composition becomes a less safe guide to the nourishing value. The nitrogen, we have already seen, is here no certain measure of the proportion of albuminoids present. The fat credited to these foods is also largely composed of waxy matters, and we can hardly attribute to it the same feeding value as to an equal amount of fat in oilcake or maize. The carbo-hydrates also include various substances of little or no feeding value. The same weight of dry matter in crude foods of this class has thus a decidedly less nourishing value than in foods consisting entirely of matured grain. Foods belonging to different classes cannot safely be compared on the basis of their composition.

An important element in the character of a food is the proportion between its nitrogenous and non-nitrogenous constituents, these two classes of ingredients performing to a considerable extent distinct functions in the body. To find this proportion it is usual to calculate the fat into its equivalent in starch (generally done by multiplying the fat by 2.44), and add the product to the other carbo-hydrates of the food; the relation of the albuminoids to the total non-nitrogenous constituents reckoned as carbo-hydrates is then easily found. The relation in question is commonly known as the "nutritive relation" of the food (Nährstoffverhältniss), but is better described as the "albuminoid ratio." Thus the composition of wheat

grain in the table shows an "albuminoid ratio" of 1 : 6.6, and the composition of decorticated cotton cake an albuminoid ratio of 1 : 1.5. Figures so calculated are, however, only approximate, as we ought clearly only to take account of the constituents actually digested by the animal. We shall therefore refer to the subject again further on.

Most foods supply a sufficient quantity of the ash constituents which are required for the formation of bone and tissue; the chief of these are phosphoric acid, lime, and potash.

The oilcakes and bran are the foods richest in phosphoric acid; straw and meadow hay are the foods poorest in this constituent. Lime is most abundant in clover hay, bean straw, and turnips, and occurs in least quantity in the cereal grains and in potatos. Potash is abundant in roots, hay, bean straw, bran, and oilcake, and is found in smallest quantity in the cereal grains.

Of all the ash constituents lime and soda are probably the most generally deficient. Maize is of all ordinary foods (rice excepted) the poorest in lime; it certainly contains too small an amount for a rapidly growing animal. At Rothamsted a mixture of coal ashes, common salt, and superphosphate was used with advantage in the case of pigs fed solely on maize. It must be recollected, however, that animals will generally receive no inconsiderable amounts of lime in their drinking water.

The proportion of phosphoric acid and potash in various foods is shown in the table on page 114.

Digestibility of Foods.—Our knowledge concerning the digestion of food by farm animals is almost entirely

derived from German investigations ; * much information has already been obtained upon this subject, though a great deal yet remains to be accomplished. The general method of investigation has been to supply an animal with weighed quantities of food, the composition of which has been ascertained by chemical analysis. During this experimental diet the solid excrements are collected and weighed, and are finally analysed by the same chemical methods previously applied to the food. Subject, therefore, to certain small corrections for intestinal secretions, we obtain by this plan the amount of each constituent of the food which has passed through the animal unabsorbed, and by difference the amount digested. The proportion of each constituent digested for 100 supplied as food is known as its "digestion coefficient."

1. **Experiments with Ruminants.**—Ruminating animals possess an extensive digesting apparatus, consisting of the well-known four stomachs, in addition to the intestinal organs. Food takes a considerable time in passing through this system. In changing the diet of an ox five days will generally elapse before the remains of the preceding diet are expelled by the animal. Animals of this class are specially adapted for the digestion of bulky foods, containing much fibre.

Experiments have been made with oxen, cows, sheep, and goats. The power of these different animals for digesting food is apparently very similar, but no accurate comparisons have as yet been made. The following table shows

* The information given in this section is taken almost entirely from the admirable work of Dr. E. Wolff, "Die Ernährung der Landwirthschaftlichen Nutzthiere," with its valuable Supplement just published.

the average results obtained with ruminating animals fed on the foods respectively mentioned. The figures given represent the "digestion coefficients" found for each constituent of the food consumed. The "albuminoid ratio" of the digested portion of the food is also given:—

EXPERIMENTS WITH CATTLE, SHEEP, AND GOATS.

Food.	Digested for 100 of each constituent supplied.					Albuminoid ratio.†
	Total organic matter.	Albuminoids.	Fat.	Soluble carbohydrates.	Fibre.	
Linseed cake	80	84	90	78	?	1 : 1·7
Beans	90	88	93	93	?	1 : 2·1
Oats	71	79	84	76	24	1 : 6·5
*Barley	81	77	100	87	?	1 : 8·2
*Maize	88	79	85	91	?	1 : 7·9
*Wheat bran	67	75	50	70	37	1 : 4·5
Meadow hay	59	56	47	62	57	1 : 9·2
Clover hay	59	55	56	69	44	1 : 6·2
Lucerne hay	59	76	38	67	40	1 : 2·8
Oat straw	51	38	30	43	61	1 : 14·7
*Wheat straw	46	20	36	39	56	1 : 44·1
*Bean straw	50	51	55	60	36	1 : 6·2

Roots and potatos are not mentioned in the table; they are apparently completely digested, with the exception perhaps of the small amount of hard fibre contained in the epidermis and rootlets.

The digestibility of the foods in the lower division of the table has been for the most part determined by

* These results are derived from one or two experiments only.

† The numbers in this column refer to the foods actually used in the experiments.

feeding the animals on these foods alone; the digestibility of the foods in the upper division has been found by supplying them in various proportions along with hay, the digestibility of which had been already ascertained with the same animal. The amount of fibre in these last-named foods is usually too small for its digestibility to be determined with certainty by a few experiments.

The concentrated foods placed in the upper part of the table are seen to be far more thoroughly digested than is the case with hay or straw. When of good quality, 80 or 90 per cent. of the organic matter of these foods will be assimilated by the animal, except in those cases where much fibre is present. The albuminoids and fat in these foods have especially a greater digestibility than the same ingredients in hay and straw. The hard fibre forming the husk of seeds is apparently but little digestible. The oats employed were of somewhat inferior quality.

In the case of ordinary hay and straw the organic matter digested is but 45 to 60 per cent. of that supplied. The minimum amount digested occurs with wheat straw; oat straw, which is generally cut somewhat more green, is distinctly more digestible. The results given for meadow and clover hay relate to hay of average quality; the lucerne hay was of better quality, and shows a much higher degree of digestibility in the nitrogenous matter.

The higher is the proportion of nitrogenous matter in hay and straw, the greater appears to be its digestiblity. Thus the wheat straw experimented with contained 4.8 per cent. of nitrogenous matter in its dry substance, of which only one-fifth, or 20 per cent., was digested; while good lucerne hay with 19.3 per cent. of nitrogenous

matter, had 76 per cent. of this in a digestible form. The precise nature of the digested and undigested nitrogenous matter has not yet been ascertained; amides being soluble bodies have probably been classed in these experiments as digestible albumin.

Of the fibre in hay and straw about 40 to 60 per cent. is generally digested by ruminant animals. The fibre of leguminous hay and straw (clover and lucerne hay, and bean straw) is considerably less digestible than the fibre of similar graminaceous foods (grass hay, oat and wheat straw). It has been shown that both in the case of the soluble carbo-hydrates, and of the fibre, the portion digested has always the general formula of starch or cellulose, $C_6H_{10}O_5$, while the portion left undigested is much richer in carbon. It appears, therefore, that while cellulose is a digestible substance, the lignose which is deposited in the tissues as the plant increases in age, and which contains a larger proportion of carbon, is indigestible. Chemical analysis shows that the fibre of leguminous hay and straw is richer in carbon, and consequently in lignose, than the fibre of grass hay, or corn straw.

We must now glance at the circumstances which influence the proportion of food digested. The individual character of the animal undoubtedly affects the proportion digested. Of two animals supplied with the same food, one will often persistently digest a larger proportion than the other. In young animals the digestive power is apparently very similar to that of animals of full age. Sheep from six to fourteen months old showed no distinct change in digestive capacity.

Differences in the quantity of the daily ration of hay do not sensibly affect the proportion digested; an animal will

not digest more by being starved. Labour also is practically without influence, horses at rest and at work digesting nearly the same proportion of their food. Differences in the quality of a food may, however, exercise a great influence on its digestibility; the addition of another food may also considerably alter the rate of digestion of the first food.

The digestibility of fodder plants is mainly determined by their age; all the constituents of a young plant are more digestible than in the same plant of greater age. The composition of meadow grass cut at three different dates has been already given on page 74; this grass was supplied to sheep in the form of hay, and yielded the following digestion coefficients:—

DIGESTION OF HAY BY SHEEP.

Date of cutting.	Proportion of each constituent digested for 100 supplied.				
	Total organic matter.	Albuminoids.	Fat.	Soluble carbohydrates.	Fibre.
May 14 . . .	75·8	73·3	65·4	75·7	79·5
June 9 . . .	64·3	72·1	51·6	61·9	65·7
,, 26 . . .	57·5	55·5	43·3	55·7	61·1

The diminution in digestibility with the increasing maturity of the grass is very striking, and is very equally spread over all the constituents. Similar experiments with clover cut at different stages of growth have yielded similar results. It follows plainly from what has been now stated that no fixed nutritive value can be applied to fodder crops, or to the hay made from them, as both their

composition and digestibility are largely influenced by their age and condition when cut. The young plant is always the most nutritive.

The superior fattening quality of a pasture, as compared with that of the hay made from it, is clearly due to the fact that on land continuously grazed the animal is entirely fed on young herbage, while hay will always consist of the fully grown plant.

Fodder crops do not sensibly diminish in digestibility by being made into hay, if haymaking is carefully carried out in good weather. But the loss of the finer parts of the plant by rough treatment, or the washing out of soluble matter by rain, may considerably diminish the digestibility. Hay appears to lose some of its digestibility by keeping.

We now turn the influence of one food on the digestibility of another.

If to a diet of hay and straw, consumed by a ruminant animal, a pure albuminoid, as wheat gluten, be added, the added food is entirely digested without the rate of digestion of the original food being sensibly altered. The same result has been obtained in experiments with pigs. These animals were fed on potatos, to which variable quantities of meat flour were afterwards added. The albuminoids of the meat were entirely digested, while the proportion of the potatos digested remained unchanged.

An addition of oil (olive, poppy, and rape oil) to a diet of hay and straw is also apparently without unfavourable influence on the rate of digestion; indeed some experiments with small quantities of oil ($\frac{1}{2}$ lb. of oil per day per 1000 lb. live weight) show an improved digestion of the dry fodder. With large additions of oil the appetite of

the animal for hay and straw is much diminished. Oil supplied in moderate quantities is itself entirely digested.

An addition of starch or sugar to a diet of hay or straw diminishes its digestibility, if the amount added exceeds 10 per cent. of the dry fodder. The albuminoids of the food suffer the greatest loss of digestibility under these circumstances; the fibre also suffers in digestibility if the amount of carbo-hydrate added is considerable. When starch has been added, it is itself completely digested if the albuminoid ratio of the whole food is not less than 1 : 8.*

These facts are of considerable practical importance. Nitrogenous foods, as oilcake and bean meal, may be given with hay and straw chaff without affecting their digestibility; but foods rich in carbo-hydrates, as potatos and mangels, cannot be given in greater proportion than 15 per cent. of the fodder (both reckoned as dry food) without more or less diminishing the digestibility of the latter. This decrease in digestibility may, however, be counteracted in great measure by supplying with the potatos or mangels some nitrogenous food. When this is done the proportion of roots or potatos may be double that just mentioned without a serious loss of digestibility. Potatos exercise a greater depressing effect on the digestibility of hay than roots, starch being more potent in this respect than sugar. The cereal grains are rich in starch, but contain also a fair proportion of albuminoids; they may be added to dry fodder without seriously affecting its digestibility, if the albuminoid ratio of the whole food does not fall below 1 : 8.*

Common salt is well known to be a useful addition to

* In this statement made by Wolff the whole of the nitrogen in the food is reckoned as albuminoid.

the food of animals. It does not apparently assist digestion, but it increases appetite; and when sodium salts are deficient in the food, it supplies the blood with a necessary constituent. Sodium salts are tolerably abundant in mangels, and small in quantity in hay; they are absent in potatos, and generally absent in grain of all kinds.

2. **Experiments with Horses.**—In recent experiments conducted by Wolff the digestive powers of horses and sheep have been accurately compared, the same food having been supplied to each set of animals.

The principal results were as follows:—

EXPERIMENTS WITH HORSES.

FOOD.	Proportion of each constituent digested for 100 supplied.				
	Total organic matter.	Albuminoids.	Fat.	Soluble carbohydrates.	Fibre.
Pasture grass	62·1	68·8	13·4	65·8	57·0
Meadow hay (very good)	51·7	64·3	23·5	56·9	42·6
Meadow hay (ordinary)	46·3	58·4	18·8	51·7	37·3
Lucerne hay	57·9	74·3	3·2	70·2	39·0
Oats	72·0	87·0	78·2	76·6	25·6
Beans	87·4	86·2	8·5	93·4	69·3
Maize	90·9	77·6	63·0	93·9	100·0

EXPERIMENTS WITH SHEEP.

Pasture grass	75·8	73·3	65·4	75·7	79·5
Meadow hay (very good)	64·7	66·6	54·5	65·6	63·5
Meadow hay (ordinary)	58·7	57·2	44·3	58·7	59·8
Lucerne hay	59·1	72·8	29·7	67·9	43·6
Oats	72·9	85·5	84·8	77·7	26·1
Beans	89·6	87·1	84·2	91·2	78·5
Maize	88·5	78·5	84·6	91·3	61·9

On comparing these figures it is evident that a horse digests meadow grass and hay less perfectly than a sheep, and the difference between them is apparently as great when the food is young grass as when ordinary hay is employed. There is little difference in the proportion of albuminoids assimilated by the two animals, but the divergence becomes very considerable when we come to the carbo-hydrates, fibre, and fat. Of the carbo-hydrates the horse digests 7—10 per cent., of the fibre 22 per cent., and of the fat and waxy matter 25—52 per cent. less than the sheep. On the whole, the horse digests about 12 per cent. less of the total organic matter of grass hay than the sheep. With lucerne hay of good quality the digestion by the horse is far better, and (save as regards the fat) nearly equals that of the sheep.

The small digestive power of the horse for vegetable fibre is plainly connected with the fact that it is not like the sheep a ruminant animal, and is thus unprovided with the same means of attacking an insoluble food. In a trial with wheat-straw chaff the horse digested 22·5, and the sheep 47·6 per cent. of the total organic matter.

With corn the digestion of the horse is apparently quite equal to that of the sheep. The beans and maize were soaked in water before they were given to the horse. Stress must not be laid on the digestion coefficients found for ingredients of the food present in small quantity, as, for instance, the fat and fibre of beans, and the fibre of maize.

3. **Experiments with Pigs.**—These have not been so numerous as those with ruminant animals. The following

table shows the digestibility ascertained for some of the common pig foods:—

EXPERIMENTS WITH PIGS.

Food.	Digested for 100 supplied.				Albuminoid ratio.†
	Total organic matter.	Albuminoids.	Fat.	Soluble carbohydrates.	
*Sour milk	97	96	95	99	1 : 2·3
*Meat flour	92	97	87	—	1 : 0·4
Pea meal	91	88	58	97	1 : 2·5
Bean meal	84	79	71	91	1 : 2·6
*Barley meal	84	79	70	90	1 : 7·0
Maize meal	91	84	76	94	1 : 8·8
Rye bran	67	66	58	75	—
Potatos	94	81	—	98	1 : 9·2

The digestive power of the pig for the foods here mentioned is very considerable, and in cases admitting of comparison appears to be fully equal to that possessed by ruminant animals. Nor is the pig incapable of digesting vegetable fibre, when this is presented in a favourable condition. Two pigs fed on green oats and vetches digested 48·9 per cent. of the fibre supplied. The digestive apparatus of a pig is not, however, adapted for dealing successfully with bulky fodder. Pigs are very capable of digesting animal food.

4. **Experiments with Geese.**—These birds have no power of digesting vegetable fibre; the food apparently passes too quickly through the system for the fibre to be attacked.

* The numbers in this case are the result of a single experiment.

† These ratios refer to the part of the food actually digested.

Comparative Nutritive Value of Foods. — Having made ourselves acquainted with the composition and degree of digestibility of the ordinary cattle foods, we may now offer some general considerations as to their relative feeding value.

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1. **Influence of proportion of Water.** — The feeding value of roots, and of other foods rich in water, is often diminished by the fact that a part of the heat they produce in the body is consumed in raising the water they supply to the temperature of the animal, and of vaporising a part of it as perspiration. With sheep the normal proportion of water to dry food is about 2 : 1; with cattle, from whose skin perspiration is more active, about 4 : 1.

A sheep feeding on turnips in winter in the open field, consuming, say, 20 lb. of roots per day, will receive in its food about 18 lb. of water, of which 14 lb. is beyond that necessary for nutrition. This 14 lb. of water has to be raised from near the freezing point to the temperature of the animal body, a rise of at least 60° Fahr. To warm the water to this extent will require the combustion of about 54 grams of carbo-hydrates, reckoned as starch, equal to about 6 per cent. of the total food consumed. The actual waste of food will, however, considerably exceed this, as a part of the extra water will be vaporised as perspiration, and to vaporise 1 lb. of water at the temperature of the animal body requires the combustion of 62 grams of starch. The consumption of an excess of water will also slightly increase the amount of albuminoids oxidised in the animal body, and thus occasion a certain amount of waste of the nitrogenous part of the food.

The economy of supplying sheep on roots or green fodder

with dry food in addition is obvious from the facts just stated; by so doing the quantity of water consumed by the animal is diminished, and its proportion in the diet brought more nearly to a normal ratio.

2. **Capacity for producing Heat and Work.**—The only basis on which the nutritive value of foods of different composition can be compared is in respect to their capacity for producing heat. The production of heat and mechanical work is the principal result which food accomplishes in the animal body; the capacity for producing heat also stands in a near relation to the capacity for producing fat. On the other hand, the amount of heat which any food is capable of producing stands in no relation to its power of increasing or renewing the nitrogenous tissues of the body. We may, however, safely assert that the amount of heat generated by the combustion of the digestible constituents of any food will be a fair guide to its nutritive value, when the diet of which it forms a part supplies a sufficient amount of digestible albuminoids, and this will be the case whenever foods are skilfully used.

According to Frankland's actual determinations of the heat-producing power of fat, albumin, and starch, their comparative values in this respect are 100, 47·4, and 43·1. The albumin is here reckoned as minus its equivalent quantity of urea, as this product of the decomposition of albumin is not burnt, but excreted by the kidneys. If, now, we take the proportions of digestible fat, albuminoids, carbo-hydrates and cellulose, supplied by any food, and multiply them by the heat coefficients just given, the sum of the products will represent the heat-producing capacity of the food when consumed in the animal body.

Taking the heat-producing capacity of maize, calculated in this manner, as 100, the values found for other foods will be as follows :—

COMPARATIVE HEAT-PRODUCING VALUE OF FOODS.

	Ordinary condition.	Perfectly dry.
Maize	100	100
Linseed cake	95	96
Beans	93	96
Barley	85	88
Oats	80	81
Wheat bran	67	69
Meadow hay	59	61
Wheat straw	47	49
Potatos	30	105
Mangels	13	100

These figures are to be taken only as approximations to the truth; their correctness mainly depends upon the accuracy of the digestion experiments with ruminant animals described in the last section. The figures given for those foods containing amides, and salts of organic acids, are undoubtedly too high. Linseed cake, from the large proportion of fat and albuminoids which it contains, would be expected to occupy a much higher position in the table; its lower rank is due to its imperfect digestibility. The table on page 80 shows that while 20 per cent. of linseed cake remains undigested, and therefore useless to the animal, only 12 per cent. of maize, and 10 per cent. of beans are thus wasted.

The general result is to show that the heat and work producing power of the more perfectly digested foods is nearly equal, if we assume the same quantity of dry food to be supplied in each case.

We should gather from these calculations that an equal

weight of maize, beans, or linseed cake will have a nearly similar feeding value if supplied to an animal receiving a sufficient amount of albuminoids in its diet, as for example if given to a sheep fed on good meadow or clover hay.

3. **Proportion of Albuminoids to Non-Albuminoids.**—A further point of great importance in determining the value of a food is the proportion between the digestible albuminoids, and the digestible non-nitrogenous constituents: this relation we have already termed the "albuminoid ratio" of the food. In calculating this relation the whole of the non-nitrogenous ingredients of the food are first reduced, as already explained, to their equivalent in starch. Taking the average composition of foods already given, and the digestibility of their constituents shown by the German experiments, the albuminoid ratios will be as under:—

PROPORTION OF NITROGENOUS TO NON-NITROGENOUS CONSTITUENTS IN THE DIGESTIBLE PART OF FOOD.

	Total nitrogen reckoned.	Amides, &c., not reckoned.
Cotton cake, decorticated	1 : 1·5	.....
Cotton cake, undecorticated	1 : 1·8	.....
Linseed cake	1 : 2·3	.....
Beans	1 : 2·4	.....
Peas	1 : 2·9	.....
Wheat bran	1 : 4·2	1 : 7·0
Oats	1 : 5·5	.....
Barley	1 : 7·6	.....
Maize	1 : 9·0	.....
Clover hay	1 : 5·9	?
Meadow hay	1 : 8·0	1 : 12·4
Swedes	1 : 5·9	1 : 13·1
Turnips	1 : 6·2	?
Mangels	1 : 8·0	1 : 31·8
Potatos	1 : 10·6	1 : 17·7
Wheat straw	1 : 64·4	?

In the first column the whole of the nitrogen in the food is reckoned as existing as albuminoids; in the second column the true albuminoids only are taken account of. In calculating the second column it has been assumed that in a digestion experiment the amides and nitrates, being soluble bodies, would be reckoned as "digestible albumin;" the amides have not, however, been reckoned among the non-albuminous constituents, their equivalent in starch not being yet known.

The figures show in a striking manner the wide differences that exist among foods as to the proportion of albuminoids which they supply, the difference being made still more considerable by the recent discovery that a large part of the nitrogen in certain foods exists as amides and not as albuminoids. Mangels now appear as a food very poor in albuminoids, whereas they were formerly supposed to supply a sufficient proportion; and the same is doubtless true of other roots not yet thoroughly examined.

The poverty of a diet of roots and straw chaff in digestible albuminoids is the true reason of the excellent effects produced by the addition of oilcake or leguminous corn. Oilcake and beans used under these circumstances have an effect far above their own intrinsic feeding value, as their presence raises the character of the whole diet, and enables the carbo-hydrates of the roots and straw to contribute to the formation of carcase.

It must be recollected that the albuminoid ratio of a food may be different for different animals if their powers of digestion are unequal. Thus the same meadow hay supplied to sheep and horses had for the former an albuminoid ratio of 1 : 9·1, and for the latter a ratio of 1 : 6·7. The horse, as we have seen, digests the nitrogenous con-

stituents of hay nearly as well as the sheep, but fails in digesting the non-nitrogenous constituents. Hay is thus a more nitrogenous food for horses than for sheep.

The proportion of albuminoids most suitable for various diets will come under consideration in the next chapter.

General Conclusions.—We have now run through the principal points which determine the value of food. A little consideration will, however, show that it is impossible to affix a definite feeding value to any food, as its practical effect must depend in great measure on the conditions under which it is employed; more especially on the kind of animal consuming it, and the general character of the diet of which it forms a part. Thus, the value of a bulky food, as hay or straw, is far greater when given to a ruminant animal, than when consumed by a horse or pig. Concentrated, easily digestible foods, as corn and oilcake, have clearly a value above their composition when added to a poor and bulky food, as straw chaff, or to a watery food like turnips, because they are the means of raising the diet to a point at which the animal will thrive. On the other hand, roots and green fodder, even when watery and poor in composition, may have a considerable effect when added in moderate proportion to dry food. The highest value is, in short, only obtained from food when it is skilfully employed.

There is, finally, a condition which we can never hope to express by figures, but which has a considerable influence on the effect of any diet; this is flavour. An agreeable flavour stimulates appetite, and probably promotes digestion. This part of the question belongs, however, rather to practice than science.

CHAPTER VIII.

RELATION OF FOOD TO ANIMAL REQUIREMENTS.

The Requirements of the Young Animal.—Composition of colostrum and milk—Suitable albuminoid ratio of the food. *The Adult Animal.*—Work, how performed—Maintenance diets—Labour diet. *The Fattening Animal.*—Conditions necessary for increase—Results obtained when fattening oxen, sheep, and pigs, on ordinary diets—Alterations in consumption of food, and rate of increase, as fattening proceeds—Albuminoid ratios for fattening animals. *Production of Wool.*—Composition of wool—Influence of diet. *Production of Milk.*—Influence of diet on the quantity and quality of the milk—Influence on the character of the butter—Albuminoid ratio for milk-cows.

The Young Growing Animal.—The special character of the nutrition of young animals is the rapid formation of nitrogenous tissue and bone, for which purpose an abundant supply of albuminoids and ash constituents in the food is clearly requisite.

The kind of food most appropriate to the wants of a young animal is shown by the composition of milk. The milk supplied to the young immediately after birth (the colostrum) is of a very concentrated description. During the first week after birth the quantity of the milk greatly increases, and its composition gradually alters from that of colostrum to that of ordinary milk.

In the following table will be found the composition of the colostrum and milk yielded by various farm animals; the numbers given are the mean of many analyses.

COMPOSITION OF COLOSTRUM.

	Water.	Albuminoids.	Fat.	Sugar.	Ash.	Albuminoid ratio.*
Ewe . . .	73·2	15·4	2·0	8·0	1·4	1 : 0·8
Sow . . .	70·1	15·6	9·5	3·8	0·9	1 : 1·7
Cow . . .	71·7	20·7	3·4	2·5	1·8	1 : 0·5

COMPOSITION OF MILK.

Ewe . . .	83·1	5·5	5·5	5·0	0·9	1 : 3·3
Sow . . .	84·6	6·3	4·8	3·4	0·9	1 : 2·3
Goat . . .	85·3	4·1	5·2	4·6	0·8	1 : 4·1
Cow . . .	87·0	4·0	3·7	4·6	0·7	1 : 3·3
Ass. . . .	90·0	2·3	1·3	6·0	0·4	1 : 3·7
Mare . . .	90·4	2·0	1·0	6·2	0·4	1 : 4·0

The colostrum is characterised by an especially high percentage of albuminoids. In milk we find a smaller proportion of albuminoids, and a larger proportion of fat and sugar. The solid matter of milk has a very high feeding value, owing to the large proportion of fat and albuminoids present, and its perfect digestibility. If we take, as before, the heat-producing capacity of dry maize as 100, then the heat-producing capacity of dry cow's milk will be 140. Milk also supplies the ash constituents necessary for the formation of bone and tissue: 100 lb. of cow's milk will supply about 0·20 lb. of phosphoric acid, 0·16 lb. of lime, and 0·17 lb. of potash.

The relation of the nitrogenous to the non-nitrogenous constituents of milk is much higher than in most vegetable foods; the analyses in the table show a relation varying

* In calculating this relation it has been assumed that 10 of milk sugar are equivalent to 9 of starch.

from 1 : 2·3 to 1 : 4·1, and the latter proportion is seldom much exceeded in any sample of milk. In supplying very young animals with artificial food the above facts must be borne in mind; the food should clearly be of an easily digestible character, and contain a considerable proportion of albuminoids and fat. Instead of this, foods rich in starch are too often employed. Linseed is perhaps, of ordinary foods, the one most similar to milk in composition.

As the animal grows the quantity of food it requires increases, at the same time a larger proportion of the food is applied to the production of heat and mechanical work; the proportion of nitrogenous matter in the food may therefore gradually be diminished, carbo-hydrates and fat being quite as fit as albuminoids for producing heat and work. Under natural conditions this diminution in the nitrogenous character of the diet soon takes place, the animal daily taking more and more grass in addition to its mother's milk. The albuminoid ratio * of the diet of rapidly growing animals may vary from 1 : 5 to 1 : 7, the more nitrogenous diet being most suitable for younger animals, or for the production of more rapid increase.

The adult Animal.—Food, we have already seen, is primarily employed for the renovation of the animal tissues, and for the production of heat and mechanical work; by far the greater portion of the food is applied to the latter purposes.

Much of the work performed by an animal is internal, and consists in the muscular movements which produce

* The albuminoid ratios henceforward given will represent, as far as possible, the proportion of true albuminoids present in the food.

circulation, respiration, and other vital processes; such work is carried on even when the animal is at rest. In man the whole of the blood is pumped through the heart every half minute. The daily work performed by the heart of an average man has been calculated as equal to 150—200 foot-tons; that is to say, the power exerted by the heart would raise 1 ton to the height of 150—200 feet. The work performed by other organs, and by the muscles when merely maintaining the body in an erect position, has not yet been satisfactorily measured.

It was formerly supposed that muscular force was produced by the oxidation of the muscle, and that a diet rich in albuminoids was consequently necessary if hard labour was to be maintained. This idea is now known to be erroneous, it having been shown by repeated experiments that labour does not necessarily increase the production of urea, while it does in every case greatly augment the amount of carbonic acid and water exhaled. Mechanical power is, in fact, produced not by oxidation of the muscle, but of the organic matter in circulation; this organic matter may be indifferently either fat, carbohydrates, or albuminoids. The animal body thus obtains the power necessary for the performance of work in the same manner as a steam engine, only that in the body food is burnt in the place of coal.

When labour is demanded from an under-fed animal, the oxidation taking place in the circulatory system may be in excess of the food supplied, and of the fat and carbohydrates in circulation; in such a case the albuminoids of the animal body are oxidised, and the excretion of urea becomes increased. A working animal ill supplied with food will thus suffer seriously in condition.

In the case of an adult animal not increasing in weight, and performing a minimum amount of work, as, for instance, a horse or ox in a stable, the quantity of food required is reduced to its smallest limits. An ox of 1000 lb. live weight, quiet in the stall, will require daily, according to the German experiments, about 0·5—0·6 lb. of digestible albuminoids,* and 7·1—8·4 lb. of digestible non-albuminous food, reckoned as starch, to preserve its condition. With sheep the maintenance diet must be more liberal, as in their case the growth of wool, with its accompanying fat, is always in progress, and is practically independent of the abundance or poverty of the diet. For 1000 lb. live weight (shorn), sheep fed on meadow hay will require about 0·9 lb. of digestible albuminoids,* and 10·8 lb. of digestible non-albuminous food, or 16—17 lb. dry organic matter, per day, to preserve their condition. If fed on mangels and straw chaff the quantity of dry organic matter must be raised to 20—25 lb. In these maintenance diets for adult animals the albuminoid ratio of the food is but 1 : 14 in the case of the ox, 1 : 12 in the case of the sheep fed on hay, and the relation is wider still in the case of the sheep fed on straw and mangels. The inferiority of the latter diet is the cause doubtless of the larger amount of food required.

If external work is to be performed, the body weight remaining unaltered, the quantity of food must be considerably increased, and the food must be of such quality that it may be possible to digest a sufficient amount in the required time. A man doing a fair day's work was

* These numbers represent true albuminoids, and are, therefore, smaller than the German figures.

found to exhale one-third more carbonic acid than when at rest; a man doing such work would clearly require one-third more food to maintain the same condition of body.

If we assume that when food is burnt in the body one-fifth of the energy developed may appear as external work, then 1 lb. of digested starch would enable an animal to perform 485 foot-tons of work, 1 lb. of digested albumin 528 foot-tons, and 1 lb. of digested fat 1127 foot-tons of work.

The recent experience of the use of maize for horses shows that an albuminoid ratio of 1 : 9 is quite sufficient for a labour diet.

The Fattening Animal.—The character of the fattening process has been more thoroughly studied than the nutrition of young and growing animals.

For the body to increase in weight it is clear that the food supplied must be in excess of the quantity demanded for mere renovation of tissue, and for the production of heat and work. When such an excess of food is given, a part of the albuminoids and ash constituents is generally converted into new tissue, while a part of the fat, carbohydrates, and albuminoids is stored up in the form of fat.

As only the excess of the food is converted into increase, liberal feeding is, within certain limits, the most economical. If a lamb can be brought by liberal treatment to 150 lb. live weight at one year old, the amount of food consumed will be far smaller than if two years are occupied in attaining the same weight, for the food required for animal heat and work during the second year is clearly saved.

Economy of food is also promoted by diminishing the demand for heat and work. An animal at rest in a stall will increase in weight far more than an animal taking active exercise on the same diet. In the same way the increase from a given weight of food will be less in winter than in spring or autumn, a far larger proportion of the food being consumed for the production of heat when the animal is living in a cold atmosphere. Hence the economy of feeding animals under cover during winter. If, however, the temperature becomes so high as to considerably increase the perspiration, waste of food again takes place, heat being consumed in the evaporation of water. The temperature most favourable for animal increase is apparently about 60° Fahr. Quietness, and freedom from excitement are essential to rapid fattening; the absence of strong light is therefore desirable.

The capacity of an animal for fattening depends much on breed and temperament. A farmer learns to recognise the fattening disposition of an animal from the feel of its skin, &c.

The three animals with which the farmer is chiefly concerned have very different powers of consuming food, and yield different rates of increase. Lawes and Gilbert reckon that, on an average of the whole fattening period, an ox will produce 100 lb. of live weight from the consumption of 250 lb. oilcake, 600 lb. clover hay, and 3500 lb. swedes. Sheep will produce the same increase by the consumption of 250 lb. oilcake, 300 lb. clover hay, and 4000 lb. swedes. Pigs will require about 500 lb. of barley meal to yield a similar result. Taking these data, the rate of food consumption, and of increase yielded will be as follows:—

RESULTS OBTAINED WITH FATTENING ANIMALS PER 100 LB. LIVE WEIGHT PER WEEK.

	Received by the animal.		Results produced.		
	Total dry food.	Digestible organic matter.	Food consumed for heat and work.*	Dry manure produced.†	Increase in live weight.
	lb.	lb.	lb.	lb.	lb.
Oxen . . .	12·5	8·9	6·86	4·56	1·13
Sheep	16·0	12·3	9·06	5·10	1·76
Pigs . . .	27·0	22·0	12·58	4·51	6·43

RESULTS OBTAINED IN RELATION TO FOOD CONSUMED.

	Increase in live weight.		On 100 lb. of dry food.		
	Per 100 lb. dry food.	Per 100 lb. digested organic matter.	Consumed for heat and work.*	Dry manure produced.†	Dry increase yielded.
	lb.	lb.	lb.	lb.	lb.
Oxen . . .	9·0	12·7	54·9	36·5	6·2
Sheep	11·0	14·3	56·6	31·9	8·0
Pigs . . .	23·8	29·2	46·6	16·7	17·6

It is evident from the upper division of the table that pigs are able to consume far more food in proportion to their weight than either sheep or oxen. This is due to the concentrated and digestible character of the food (corn meal) supplied to a fattening pig, and to the great capacity of this animal for assimilation. The proportion

* In calculating the amount of food consumed for the production of heat and work, it has been assumed that the fat in the increase has been derived entirely from the fat and carbo-hydrates supplied by the food.

† The manure is exclusive of litter.

of stomach is greater in a fat ox or sheep than in a pig, being on 100 lb. live weight, 3·2 for the ox, 2·5 for the sheep, and 0·7 for the pig. On the other hand, the proportion of the intestines is greater with the pig than with sheep or oxen. Ruminant animals are thus best fitted for dealing with food requiring a prolonged digestion, while the pig excels in the capacity for assimilation.

As a natural result of the larger consumption of food the pig increases in weight much more speedily than either the sheep or ox; but not only is the rate of increase more rapid, the increase yielded by the pig is also far greater in proportion to the food received, as plainly appears from the lower division of the table. The pig with its very large consumption of food has, in fact, to spend a smaller proportion of it on heat and work, and has thus a large surplus left to store up as increase. Of 100 lb. digested organic matter, the fattening ox spends about 77 for heat and work, the sheep 74, and the pig 57. The upper division of the table shows, however, that in a given time a pig does convert a much larger amount of food into heat and work than either sheep or ox; this greater consumption probably represents internal work performed in the laying on of increase. The pig, with its rapid feeding, and high rate of increase, is undoubtedly the most economical meat-making machine at the farmer's disposal.

The results given by sheep are seen to lie in nearly every case between those given by oxen and pigs, being however much nearer to the former than to the latter. The German experiments place the sheep below the ox as an economic producer of increase, instead of above it, as in the Rothamsted statistics just quoted; the difference is

probably due to the different breeds of animals experimented with. The influence both of breed, and of the individual character of the animal on the rate of increase whilst fattening is very considerable.

The results relating to manure will be discussed in the next chapter.

We have hitherto looked at the fattening period as a whole; the rates of consumption and of increase are, however, very different in different stages of this period.

As a fattening animal increases in size the quantity of food it consumes also somewhat increases, the requirements of the body for heat and renovation of tissue becoming greater as its weight and size are increased; the stomach at the same time becomes larger. When the animal becomes very fat, the consumption of food falls off again, the rate of increase at this point being much diminished.

As fattening advances the daily increase in live weight becomes gradually smaller, and the same amount of food will produce a steadily diminishing amount of increase. This is partly because the increase during the later stages of fattening is drier, and contains a larger proportion of fat than in the earlier stages of the process. Partly also because the consumption of food for heat and work is increased with the increasing size of the body. More internal work must also be performed to add increase to a large animal than to a small one. These changes in the rates of consumption and increase are seen more strikingly in the case of pigs than with other animals, from the greater rapidity of the fattening process. The following table shows the average results obtained on sixteen pigs fattened at Rothamsted at the same time, the food being 7 lb. of pea meal per head per week, with an unlimited

unwashed fleece; but in the case of ordinary sheep, freely exposed to weather, the quantity may be 15 per cent., or less. In a washed fleece the fat may vary from more than 30 per cent. to 8 per cent., or less. Short fine wool contains the largest proportion of fat. Pure wool hair contains about 16 per cent. of nitrogen. The quantity of nitrogen and ash constituents in unwashed wool has been already given on page 63.

The production of wool-hair and of wool-fat is practically no greater when sheep receive a liberal fattening diet, than when the diet only suffices to maintain the ordinary condition of the animal; indeed, under poor treatment, the carcase may lose weight to some extent without the production of wool being seriously altered. With starvation, however, the yield of wool is considerably diminished. If sheep are kept on a poor diet for the mere production of wool, the amount of albuminoids supplied must not fall too low, wool-hair being formed entirely from this part of the food.

Production of Milk.—The quantity of milk produced is largely determined by the individual character of the animal, and on the length of time which has elapsed since birth; the quality of the milk is also affected, though to a less extent, by the same conditions. Subject to these natural limitations, both quantity and quality are greatly influenced by the character of the food supplied.

A liberal diet is essential for a full supply of milk. Green fodder is favourable to a large produce, so also are brewers' grains. The diet of a milking cow should vary with the yield of milk, the object being to obtain as large a yield as can be reached without fattening the animal.

The quality of the milk is considerably influenced by the richness of the diet. A diet of watery grass will probably yield a moderate quantity of poor milk, the addition of oilcake will increase both the yield of milk and also its richness. The alteration in the composition of milk by poor or liberal feeding is chiefly an alteration in the percentage of solid matter; the relative proportions of casein, butter, and sugar are scarcely affected by the character of the diet.

The quality of the butter is more or less influenced by the character of the food, some foods producing a hard, and others a soft butter. Rape cake, oats, and wheat bran are reckoned in Denmark as first-class butter foods; palm nut cake and barley as second-class foods; while linseed cake, peas, and rye are placed in the third class. The first-class foods produce a soft butter, the third class foods a hard butter. By the employment of first and second class foods with straw chaff, hay, and roots, an abundance of excellent butter may be produced throughout the winter. Turnips strongly flavour both milk and butter; mangels are a better food for milk cows.

As milk is a product far more nitrogenous than the increase of carcase obtained when an animal is fattened, cows in full milk will require a tolerably nitrogenous diet. Such a diet is naturally provided when cows feed on young grass and clover; when hay, straw, and roots form the bulk of the food, it is imperative that cake or corn be also employed if abundance of milk is desired. Wolff gives 1 : 5 as the albuminoid ratio most suitable for the diet of cows in full milk: deducting amides, the ratio will probably be about 1 : 6—7.

CHAPTER IX.

RELATION OF FOOD TO MANURE.

The quantity of manure produced by oxen, sheep, and pigs, under given diets—Proportion of the ash constituents and nitrogen of the food which appears in the liquid and solid excrements—Composition of the excrements of sheep and oxen—The relative manure value of various cattle foods—The value of the ash constituents and nitrogen of animal manure as compared with the same materials in artificial manures.

THE quantity of dry manure produced for a given quantity of food consumed has been already mentioned. The figures in the table on p. 102 show that, with the diets assumed, the sheep produces for the same weight of dry food nearly twice as much manure as the pig, while the ox produces even more manure than the sheep. This difference is due to the less digestible character of the food supplied to the sheep and ox. The quantity of manure produced during the same time, and for the same body weight, is however very similar with the three animals, the greater consumption of food by the pig counterbalancing its lower rate of manure production.

The only constituents of food which are of importance as ingredients of manure are the nitrogenous substances, and the ash constituents. If the live weight of an animal remains unchanged, and there is no production of milk, the quantity of nitrogen and ash constituents voided in

the manure will be the same as that contained in the food consumed; the albuminoids and ash constituents of the food used for the renovation of tissue being in this case equivalent to the quantity yielded by the degradation of tissue. In cases where the body weight is increasing, or milk is being produced, the amount of nitrogen and ash constituents in the manure will be less than that in the food in direct proportion to the quantity of these substances which has been converted into animal produce.

A part of the albuminoids and ash constituents is left undigested during the passage of the food through the alimentary canal; these are voided in the solid excrement. The digested nitrogenous matter and ash constituents pass into the blood, a part of them may be converted into animal increase if the animal is gaining in weight or producing milk, and the remainder is finally separated from the blood by the kidneys, and is voided in the form of urine. The albuminoids and amides are oxidised into urea before being expelled from the system. In the case of herbivorous animals hippuric acid is also formed in variable quantities, and is found as an ingredient of the urine.

The proportion of the nitrogen in the food which will appear in the solid excrement is determined by the digestion coefficient of the albuminoids. Thus 79 has been already given as the digestion coefficient of the albuminoids of barley meal when consumed by a pig; it follows that in this case for 100 of albuminoids consumed 21 will be voided in the solid excrement, and 79 pass into the blood. It has been already stated that 500 lb. of barley meal, containing about 53 lb. of albuminoids, will in the case of the pig produce 100 lb. of animal increase, con-

taining 7·8 lb. of albuminoids. It follows from these data that for 100 lb. of albuminoids consumed, 14·7 are stored up as carcase, 21 appear in the solid excrement, and 64·3 as urea, &c., in the urine. In the same way, by deducting the ash constituents stored up from those present in the food, we can arrive at the quantity of ash constituents voided in the manure. Calculating in this manner the relation of food to manure in the case of the fattening ox, sheep, and pig receiving the diets assumed in previous calculations (p. 101), we arrive at the following conclusions:—

NITROGEN STORED UP AND VOIDED FOR 100 CONSUMED.

	Stored up as increase.	Voided as solid excrement.*	Voided as liquid excrement.	In total excrement.
Oxen	3·9	22·6	73·5	96·1
Sheep	4·3	16·7	79·0	95·7
Pigs	14·7	21·0	64·3	85·3

ASH CONSTITUENTS STORED UP AND VOIDED FOR 100 CONSUMED.

	Stored up as increase.	Voided in total excrements.
Oxen	2·3	97·7
Sheep	3·8	96·2
Pigs	4·5	95·5

The proportion of the nitrogen and ash constituents of

* The quantities of nitrogen given in this column are a little below the truth, as besides the undigested albuminoids some nitrogenous biliary matter is present in the solid excrement. With oxen and sheep the amount of biliary matter in the excrement is very small; with pigs it is more considerable. In the case of the pig the nitrogen in the solid excrement should probably stand as 25·0, and that in the liquid as 59·3.

the food which is stored up in the body of a fattening animal is in all cases very small. In the case of each animal mentioned in the above tables more than 95 per cent. of the ash constituents of the food find their way into the manure. With oxen and sheep more than 95 per cent. of the nitrogen of the food are likewise thus voided. The pig is seen to retain the largest proportion of the nitrogen of its food; this is clearly owing to the greater proportion of increase which the pig produces for a given weight of food consumed.

The amount of nitrogen voided in the urine is seen to be three or four times the quantity contained in the solid excrement. This relation will vary greatly according to the character of the diet. If the food is nitrogenous, and easily digested, the nitrogen in the urine will greatly preponderate; if, on the other hand, the food is one imperfectly digested, the nitrogen in the solid excrement may form the larger quantity. When ordinary hay is the diet, the nitrogen in the solid excrement will generally somewhat exceed that contained in the urine; with a straw diet the excess in the solid excrement will be much greater. On the other hand, corn and cake, and especially roots, yield a large excess of nitrogen in the urine.

The ash constituents are very differently distributed in the solid excrement and urine; in the former the lime, magnesia, and phosphoric acid are chiefly found, while the latter contains nearly all the potash. With sheep fed on hay, about 95 per cent. of the lime contained in the food, 70 per cent. of the magnesia, and 83 per cent. of the phosphoric acid were found in the solid excrement, but only 3 per cent. of the potash.

A fair idea of the general composition of the solid excre-

ment and of the urine, is given by the following table. The sheep were fed on meadow hay; the oxen on clover-hay, and oat straw, with about 8 lb. of beans per day.

PERCENTAGE COMPOSITION OF SOLID AND LIQUID EXCREMENT.
SHEEP FED ON HAY.

	Solid excrement.		Urine.	
	Fresh.	Dry.	Fresh.	Dry.
Water	66·2	...	85·7	...
Organic matter . . .	30·3	89·6	8·7	61·0
Ash	3·5	10·4	5·6	39·0
Nitrogen	0·7	2·0	1·4	9·6

OXEN WITH NITROGENOUS DIET.

	Solid excrement.		Urine.	
	Fresh.	Dry.	Fresh.	Dry.
Water	86·3	...	94·1	...
Organic matter . . .	12·3	89·7	3·7	63·0
Ash	1·4	10·3	2·2	37·0
Nitrogen	0·3	1·9	1·2	20·6

Both the solid and liquid excrements of the sheep are far drier, and therefore more concentrated, than those of the ox, whose food includes a much larger quantity of water.

The extreme richness of the urine, both in ash constituents and nitrogen, is very evident. In the case of the more highly-fed oxen, the dry matter of the urine is seen to contain over 20 per cent. of nitrogen.

The relative value of the manure produced by different foods is determined by the relative richness of the foods in nitrogen and ash constituents, but chiefly by the amount of nitrogen, this being the most costly ingredient of purchased manure. The average amount of nitrogen, and of the two most important ash constituents contained in ordinary cattle foods, is shown in the following table:—

MANURIAL CONSTITUENTS IN 1000 PARTS OF ORDINARY FOODS.

	Dry matter.	Nitrogen.	Potash.	Phosphoric acid.
Cotton cake (decorticated)	900	66·0	15·0 ?	31·2
Rape cake	900	48·0	13·2	24·6
Linseed cake	880	45·0	14·7	19·6
Cotton cake (undecorticated)	885	39·0	20·1	22·9
Linseed	905	36·0	12·3	15·4
Palm-kernel meal (English)	930	25·0	5·5	12·2
Beans	855	41·0	12·0	11·6
Peas	857	36·0	9·8	8·8
Malt dust	905	38·0	19·5	17·2
Bran	865	22·0	14·8	32·3
Oats	870	20·6	4·5	6·2
Wheat	856	18·8	5·4	8·0
Barley	860	17·0	4·9	7·3
Maize	886	16·6	3·6	6·1
Clover hay	840	19·7	19·5	5·6
Meadow hay	857	15·5	16·8	3·8
Bean straw	840	10·0	25·9	4·1
Wheat straw	857	4·8	5·8	2·6
Barley straw	850	5·0	9·7	2·0
Oat straw	830	5·0	10·4	2·5
Potatos	250	3·4	5·6	1·8
Mangels	115	1·9	3·9	0·7
Swedes	107	2·4	2·0	0·6
Carrots	142	1·6	3·2	1·0
Turnips	83	1·8	2·9	0·6

The oilcakes yield the richest manure, as they contain the largest amount of nitrogen and phosphoric acid, with a considerable amount of potash. Next to these come the leguminous seeds, malt-dust, and bran. Clover hay yields a richer manure than the cereal grains, while meadow hay stands below them. The cereal grains and the roots contain about the same proportion of nitrogen in their dry substance; the roots, however, supply much more potash. Potatos stand below roots in manurial value. Straw takes the lowest place as a manure-yielding food ; bean and pea straw are more valuable for this purpose than the straw of the cereals.

The ash constituents present in animal manure have probably the full money value of the same constituents in artificial manures, but the nitrogen has on the whole a lower value than the nitrogen of ammonium salts or nitrate of sodium. The nitrogen of the urine is indeed quite as valuable as the nitrogen of ammonium salts. When applied to soil the nitrogen of urine is rapidly converted into nitrates, the form of nitrogen most suitable for plant nourishment. But, on the other hand, the nitrogen of the solid excrements is not in a form suitable for plant food, and will be very slowly converted into nitrates in the soil.

Animal manure is probably more immediately available for the use of plants when applied directly to the land, than when previously mixed with a great bulk of litter. Fermentation with litter probably results in the formation of nitrogenous humus compounds, which are insoluble, and decompose but slowly in the soil.

The feeding of animals on the land is a mode of applying

manure which has many advantages; but the distribution of the manure is in this case irregular, and if carried out in autumn or winter the manure is subject to loss by drainage. The most effective plan of application is doubtless as liquid manure to growing crops. In winter time, however, the use of litter, and the preparation of farmyard manure (best under cover), becomes a necessity, and is on the whole the best course to adopt.

CHAPTER X.

THE DAIRY.

The constituents of milk—The conditions affecting its richness—The fat globules—Modes of raising cream—Composition of cream—Composition of skim-milk—Churning—Composition of butter—Butter-milk—Manufacture of cheese—Composition of cheese—Whey—Necessity for cleanliness.

Milk.—The general composition of colostrum, and of ordinary cow's milk, has been already given on p. 96.

The albuminoids of milk embrace two constituents of similar composition, casein and albumin. Casein is coagulated by the addition of acids, or by rennet, but not by boiling. Albumin is not coagulated by rennet, or by most acids, but is coagulated by heat. In colostrum albumin largely preponderates, so that the milk coagulates on boiling; in ordinary cow's milk the albumin forms but one-ninth of the total albuminoids.

The fat of milk chiefly consists of the glycerides of palmitic and oleic acid. The glycerides of stearic, myristic, lauric, capric, capryllic, caproic, and butyric acid are also present in small quantity. The last four of these acids are, when in the free state, more or less soluble in water. The glycerides of oleic acid and of the soluble fatty acids, are fluid fats at ordinary temperatures, the remaining fats are solid. The proportion of fluid and solid fats varies some-

what with the diet and condition of the animal; in summer time the proportion of fluid fats is greater than in winter.

The sugar contained in milk is known by chemists as lactose. When milk turns sour the lactose is converted into lactic acid; this acidification of the milk induces the coagulation of the casein, and the milk curdles. The ordinary souring of milk is the work of a ferment, *Bacterium lactis;* when this ferment is excluded no souring takes place.

Cow's milk has generally a specific gravity between 1·028 and 1·032. As the removal of cream raises the specific gravity, which can be brought back to the normal point by the addition of water, no safe conclusion as to the quality of milk can be based on this indication.

The composition of cow's milk is affected by various circumstances; under extreme conditions it may contain from 10 to 16 per cent. of dry matter. The milk is poorer when the quantity produced is large, or the diet insufficient, and richer when these conditions are reversed. A cow is generally in full milk from the second to the seventh week after calving; after this period the milk gradually diminishes in quantity, but increases in richness. A separation of cream takes place in the udder; the milk first drawn is poor in fat, and the richness increases as milking proceeds, the last drawn milk containing two or three times as much fat as the first drawn. The milk of old cows is said to be poorer than the milk of young cows.

The relation of food to the production of milk and butter has been already considered (p. 107).

Cream.—The fat of milk occurs in the form of globules;

the largest are about ·0005 to ·0006 inch in diameter, the smallest may be one-tenth this diameter, or even less. The average size of the globules is different with different breeds of cattle. The size appears to diminsh as the time from calving increases. The fat globules are in most cases coated with a thin albuminous covering. As the fat globules have a lower specific gravity than the serum in which they float, they tend to rise to the surface, where they form a layer of cream. The largest globules are the first to rise, the smallest never rise at all, being too heavily weighted by their albuminous covering. Milk containing an abundance of large globules is best for butter-making, as the cream then quickly and perfectly rises; but milk with small globules is probably best for cheese-making, as a more even distribution of fat throughout the curd is then obtained.

Milk, when it leaves the cow, will have a temperature of about 90° Fahr.; when set for cream it should be cooled as quickly as possible, as changes in composition would rapidly occur at a high temperature. Milk is usually set for cream in shallow vessels, the depth of milk being perhaps 3 inches; in these vessels the milk stands for thirty-six to forty-eight hours, till the cream has separated. Under these conditions a large surface is exposed to the influence of air, and a maximum amount of change takes place; the result is a decomposition of a part of the albuminoids and fats, the production of lactic acid, and the partial curdling of the milk. The cream obtained in this way is contaminated with curd, and contains various strongly flavoured products of decomposition, which deteriorate the quality of the butter.

On Swartz's plan the milk is placed in metal pails,

16 inches deep, and surrounded by ice. The cream rises quickly, and can all be obtained in twelve to twenty-four hours from the time of setting. Cream thus prepared is perfectly sweet, and free from curd, the low temperature at which the milk has been kept having reduced chemical change to a minimum. It occasionally happens that milk will not yield its cream at low temperatures; this is sometimes the case with the milk of cows several months after calving, and especially when receiving a winter diet.

A third plan of separating cream is by subjecting the milk to extremely rapid horizontal revolution in a centrifugal machine; under these circumstances the fat globules rise into the centre of the revolving mass. In Laval's machine the new milk enters in a continuous stream, and is immediately separated into cream and skim-milk, the former leaving the apparatus by a pipe at the top, the latter by another pipe from the side. The cream thus obtained is, of course, perfectly sweet.

Cream varies considerably in composition. Good cream, not scalded on the Devonshire plan, may contain 55 to 65 per cent. of water, and 25 to 40 per cent. of fat. Casein and the other constituents of milk are present in small quantity. In sweet cream the casein may be about one-tenth of the fat; in cream which has soured during setting the casein forms a much larger proportion.

Skim-Milk.—Milk thoroughly skimmed in the ordinary way will contain about 0·8 per cent. of fat; more than this quantity is frequently present. When ice has been used, the percentage of fat left in the milk will be 0·3 to 0·6; and when the centrifugal machine has been employed,

0·2 to 0·5. The two latter processes are thus the most effective for the removal of cream. Ordinary skim-milk will contain about as follows :—Water, 90·0 ; albuminoids, 3·7 ; fat, 0·8 ; sugar, 4·8 ; ash, 0·7. Its specific gravity is generally 1·034 to 1·037. Skim-milk is a very nitrogenous food, the albuminoid ratio being as high as 1 : 1·7.

Butter.—The object of butter-making is to bring about the union of the fat globules which in milk and cream have existed separate from each other. The skilled butter-maker is not, however, satisfied with producing a solid mass of butter-fat ; for butter to be of good quality it must possess a certain texture and grain, and be neither hard nor greasy ; this desired result can only be attained by churning at a favourable temperature. If the temperature of the cream is too low, the butter will be long in coming, and will be hard in texture. If the temperature is too high the butter will come very speedily, but the product will be greasy, destitute of grain, and deficient in quantity. No temperature can be fixed as the best at which churning should always take place. The proportion of solid and fluid fats in the milk varies somewhat with the diet of the cows, and this necessitates a change in the temperature. A rather higher temperature will be required in winter than summer ; the temperature must also be higher for sour cream than for sweet cream. Generally speaking, perfectly sweet cream should be placed in the churn at 50° to 55° Fahr., and sour cream at 52° to 60°. When sour milk is churned for butter the temperature must be about 65°. The exact temperature most suitable for churning may be ascertained by recording every day the temperature employed, with the length of

time occupied in churning, and the amount and character of the produce; when this is done the temperature for each day can be regulated from the experience of the preceding working. The temperature will rise several degrees during churning.

Churning must always be stopped as soon as the butter comes, any over churning spoils the texture of the butter. The butter is then separated from the buttermilk, washed with cold water, and after standing to solidify is carefully worked and pressed to expel all watery matter; over-working in this stage will also spoil the grain, and make the butter greasy. Butter made from perfectly sweet cream keeps far better than butter made from sour cream, as the latter always contains curd, a substance very prone to change. Salt is generally added to improve the keeping quality of butter.

First-class butter will contain about 10 per cent. of water, and not more than 0·5 per cent. of casein, but in ordinary butter these proportions are greatly exceeded. Of the fatty acids in butter about 6 per cent. are soluble in water when separated from the glycerol with which they are combined; this fact serves to distinguish butter from other animal fats in which soluble fatty acids are absent. When butter becomes rancid the glycerides of the fatty acids are partly decomposed, and the fatty acids liberated; the odour and flavour of rancid butter are largely due to free butyric acid.

Buttermilk.—The liquid remaining in the churn after the separation of the butter from the cream has been but little investigated; it must vary a good deal in composition. Danish experimenters found that when churning the

cream from 100 lb. of new milk ·07 to ·20 lb. of fat was left in the buttermilk.

Cheese.—This substance is prepared by the action of rennet on milk. The rennet solidifies the milk by separating the casein from solution; the fat globules are separated at the same time, being entangled in the curd formed. Rennet is a watery extract prepared from the fourth stomach of the calf; its power of coagulating milk is apparently due to the presence of a ferment, which doubtless plays a similar part in the ordinary process of digestion in the calf's stomach. The action of rennet is very slow in the case of cold milk, it becomes much more energetic as the temperature rises; at 135° Fahr. it ceases to act. Milk becomes sour when curdled by rennet, but the production of acid (lactic acid) is not essential to the curdling.

The composition of cheese depends principally on that of the milk from which it is made; rich cheese is made from new milk, cream being sometimes added to the milk for the production of the richest sorts; poorer kinds of cheese are made from milk wholly or partially skimmed.

The temperature at which the milk is curdled is of great importance. If the temperature is low, the curd is very tender and the whey difficult to separate; if, on the other hand, the heat is too great, the curd shrinks too much, and becomes hard and dry. A temperature from 74° to 84° is generally employed, the lower temperature for thin cheeses, the higher (80° to 84°) for thick.

When the curd is sufficiently firm it is carefully cut in all directions, and the whey allowed to drain off. To facilitate the drainage of the whey the curd is often

heated after cutting, with the view of making it shrink and harden; the temperature used at this point must not exceed 100° Fahr. The drained and broken curd is next put into a press, to remove more effectually the last portions of whey. It is then pulverised in a mill, salted, again passed through the mill, and is then ready for filling into the frames. Curd when put into the frames should contain, according to Voelcker, about 54 per cent. of water when thin cheese is to be made, and not more than 45 per cent. if thick cheese is manufactured. The curd from skim milk will contain much more water than a curd rich in butter. The frames filled with curd are subjected to a gradually increasing pressure for several days. The cheese is then removed from the frame and placed in the cheese-room to ripen.

Cheese ripens best at a moderately warm temperature; about 70° is a suitable degree of heat. During the operation a loss of water takes place, the loss being greatest in the case of poor cheese. If decay, or a growth of mould occurs, a further considerable loss of weight takes place, the casein and fat of the cheese being decomposed by the organic life thus introduced, while carbonic acid, ammonia, and a variety of other products are formed. It was once believed that fat was produced during the ripening of cheese; this however is not the case.

A very rich cheese, as old Stilton, may contain about 20 per cent. of water, 44 per cent. of fat, and about 29 per cent. of casein. In a good Cheddar or Cheshire cheese we should find about 33 per cent. of water, 33 per cent. of fat, 28 per cent. of casein, and about 3 to 4 per cent. of ash constituents, nearly half of which would be common salt. In skim-milk cheeses the percentage of

water is greater, and that of fat less. Thus a poor single Gloucester may contain 38 per cent. of water, 22 per cent. of fat, and 31 per cent. of casein. In skim-milk cheese made in Denmark, from milk from which the cream has been very completely removed by the ice system, only 4 to 5 per cent. of fat are present.

Whey.—The whey which drains from the curd in cheese-making is a perfectly transparent liquid, containing the sugar and albumin originally present in the milk ; it should not contain more than a trace of butter. If, however, the curd has been roughly treated, the milk has been rich, and the temperature high, larger quantities of butter will be present, and the cheese suffer in consequence. When whey is rich in butter it is generally allowed to stand till the butter has risen ; the butter may then be added to the next churning. The average composition of whey is shown by Voelcker's analyses to be as follows :—Water, 93·0 ; albuminoids, 1·0 ; fat, 0·3 ; sugar and lactic acid, 5·0 ; ash, 0·7. The albuminoid ratio is 1 : 5·2.

In all the operations of the dairy the greatest cleanliness must be observed ; all vessels should be washed with hot water as soon as done with, to destroy any adhering ferment. Without such precautions no good butter or cheese can be made.

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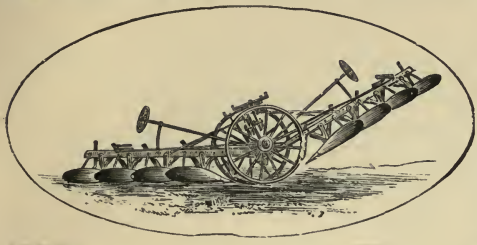

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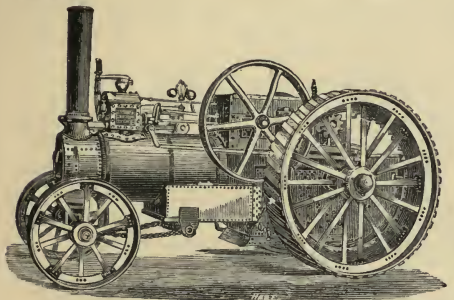

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